

CLAUDE CULPIN

FARM

MACHINERY

TWELFTH EDITION



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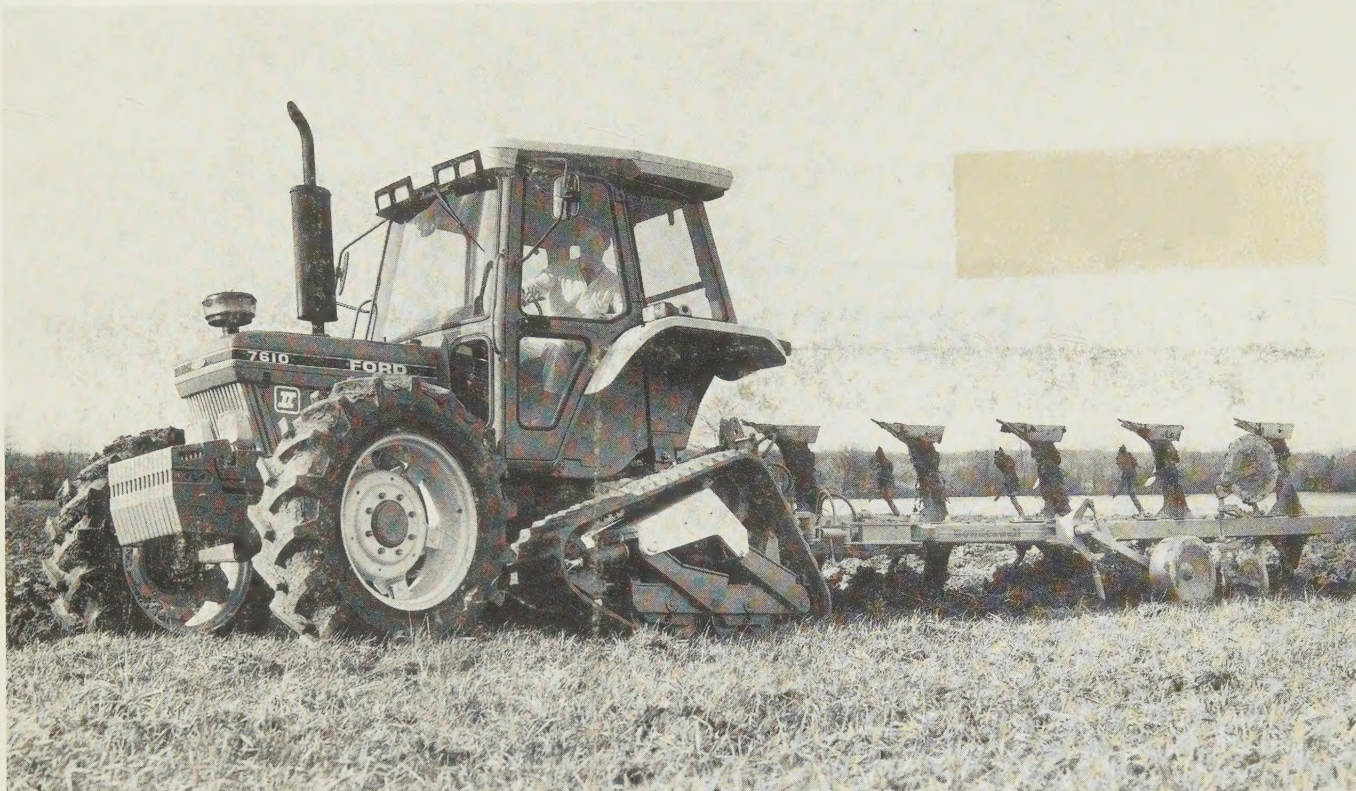
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Tractors with full rubber tracks capable of running direct from fields to public highways are dealt with in the usual way in Chapters 1 and 2. They tend at present to be heavy specialist machines of 200 hp or more, and employed mainly by large-scale farmers for heavy cultivations, or by contractors for similar specialist services.

The *Frontispiece* for the 12th Edition is devoted to a development of very high potential interest with a considerably wider scope for general application owing to the fact that the Suspended Rubber Half-track prototype developed by the Silsoe Research Institute's

Terramechanics Group is based on important new patented designs developed to suit conversion of typical large-scale production four-wheel-drive tractors with engine outputs in the region of 75 kW. The new design is based on the results of MAFF-funded research. The new half-track has some important patented features, including a parallel-link air spring suspension system with two hydraulic dampers per side which provide a remarkably smooth ride at normal tractor operating speeds.

Parallel-link geometry causes the suspension to be virtually unaffected by draught loads applied to the tractor. A patented compensation system maintains constant track tension despite the changes in track geometry due to the suspension movements. The imported rubber tracks with steel reinforcement are chosen to operate at a track width (400 mm) equivalent to that of a pneumatic traction tyre, being designed to run in the furrow when using a typical five-furrow reversible mounted plough.

The Bridgestone track construction comprises steel cords and metal segments, totally enclosed in a moulded rubber casing. The embedded metal segments are not joined in any way; all tensile loading is taken

by the steel cords. The sprocket transmits drive to the embedded metal, which in turn transfers it to the rubber track. The track is designed to accept sprockets mounted directly on the existing tractor axle flanges, so eliminating any slip between sprocket and track. Improved track designs are being developed to minimise internal power losses by friction within the track itself.

The space taken up by the present design is significantly less than that needed by a 75 kW tractor drive wheel; and direct field comparisons show substantially improved tractive performance by the half-track vehicle, with its ground contact area twice as long as that of the standard drive wheel. Design of the front end of the track provides appreciably reduced rolling resistance by the half-tracks; and field work direct comparisons have shown an overall increase of 15–25% higher work rate compared with the standard four-wheel-drive.

Up-dated detailed information is available from Drs Mike Dwyer and Andy Scarlett at Silsoe Research Institute, or on commercial production licences from Hugh Stirling of British Technology Group. The present prototype design has been fairly quickly produced by Silsoe Research Institute with co-operation from a leading tractor manufacturer. For the present, readers are advised to focus attention on the advanced design *principles* involved in this new product, which appear certain to become a commercial success. It is for such reasons that I justify departure from my normal practice over the 53-year life of this book, by illustrating a machine not available for commercial sale at the time of writing (in July 1991). I am confident that the principles of this half-track design will be adopted by several major manufacturers before the century ends.

FARM MACHINERY

Twelfth Edition

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OXFORD

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Preface to the Twelfth Edition

This edition, like the Eleventh revised for publication in 1986, is written for farmers and those who advise them; students of agriculture, farm mechanisation and agricultural engineering; and staff concerned with technical aspects of development, supply or operation of power and machinery for crop and livestock production.

Scope of the work reflects a continuation of the spate of new mechanisation developments mentioned in the Eleventh Edition, including a great expansion of successful use of electronic instrumentation and microprocessors on mobile power units and machines. A remarkable number of manufacturers of tractors, tillage equipment, drills, sprayers, harvesters and machines involved in livestock production have begun their recent design projects with a clean sheet of paper and sound knowledge of what potential users need. Without intending to spend much time on rewriting I have been impelled by the pace of progress in good new designs to make a thorough revision where

needed to highlight sound new trends, as in simultaneous use of multipurpose power outlets in medium or high-powered all-purpose tractor designs, where this can result not only in highly economic use of the operator's time but also avoids unnecessary and often harmful running over recently tilled soils by heavily loaded tractor wheels.

I have, as always, aimed to deal with basic principles where helpful, and normally to illustrate machines that are proven in practice. Inevitably there are sometimes better machines or better illustrated alternative machines that might have been used. Choice and use of illustrations does not indicate expression of opinion concerning relative merits of competitive similar products.

Claude Culpin
Silsoe
Bedfordshire

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The author wishes to acknowledge valuable assistance kindly given by many individuals and firms in preparation of the illustrations and in supplying information. Where possible the names of manufacturing firms or suppliers of copyright photographs are indicated beneath the respective illustrations.

The cover pictures were chosen from a wealth of possibilities intended to illustrate the continuing progress in mechanisation based to a considerable extent on products of UK manufacturers. Both show equipment proved in commercial use, described in the appropriate Chapters (3, 5 and 13), and already honoured in the well administered main Machinery Awards scheme operated by the RASE. The frontispiece on this occasion is accompanied by an unaccustomed personal explanatory note.

It is a pleasure to express appreciation of benefits again received from consultation with friends, several of whom helped with earlier editions. Wilf Klinner again contributed notes on forage conditioning trends (Chapter 11) and also on use of grain stripping equipment (Chapter 14): the late Roger Arnold was well and active when he again helped at length on combine harvesters (Chapter 14). Peter Redman (ADAS Engineering Devel-

opment Unit at Silsoe Research Institute) contributed to current trends in silage making and feeding (Chapter 12), and David Bartlett (ADAS at SRI) again checked Chapter 23 (Environment control). Drs Mike Dwyer and Andy Scarlett of Silsoe Research Institute (SRI) helped with information and opinions on tractor design trends. Dr Paul Miller (SRI) kindly read and commented on my account of the Institute's work on crop protection equipment developments (Chapter 9), and Peter Moran (SRI) checked my report on the Institute's work on a new mobile chicken catcher now in commercial production and in use on farms (Chapter 19).

I am much indebted to Ian Allin, Technical Officer of the Agricultural Engineers Association, who kindly provided an authoritative and up-dated revision in Appendix 6 of my selected list of British and ISO Agricultural Machinery Standards.

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Tractors: Use in Farming

Developments in modern tractors

This chapter deals with the part played by multi-purpose agricultural tractors in farming. Such vehicles show no sign of having come to the end of their development, and it is worthwhile for progressive users occasionally to stand back and review their own techniques with a view to deciding whether advantage should be taken of particular new design trends. More detail of a few selected constructional aspects may be found in Chapter 2, and in the Appendix 2.

Self-propelled machines and mechanical handling vehicles are considered mainly in the chapters dealing with particular crops or operations. Preliminary comment draws attention to a few items considered important, where new designs have come to fruition, and the quality of modern products is incomparably higher than that of machines bought only a few years ago.

The impact of four-wheel-drive

Four-wheel-drive is not new, but during the last decade high-class engineering has so improved the quality of the machines available that it now seems remarkable that the gestation period was so long. Factors which have favoured widespread recent success include the activities of specialist driven front axle manufacturers who have developed, tested and marketed to tractor makers reliable and reasonably priced complete front axles, fitted to order with suitable automatic differential gears for the front wheel drive trains.

A minimum aim of leading tractor manufacturers serving USA, UK and Western European markets is now usually to provide clutch-less gear change speeds within synchromesh boxes operated simply by pushing a short hydraulic

control lever, with an optional similar lever used for forward-to-reverse shuttle changes for loader work.

Power-shift transmissions with automatic electronic controls

An outstanding development during the 1980s was the way in which leading manufacturers took on full electronic instrumentation and use of built-in microprocessors.

The time was ripe for this in that the best Q-cabs already did much more for drivers than minimising injuries from overturning accidents. High-class suspended seats to reduce operator vibration, sound insulation to reasonable prescribed maximum levels and steering columns adjustable for both length and angle were already widely used. When the first 'intelligent' tractors were offered to potential users it was understandable that the extra cost of top-of-range models should persuade some potential users to prefer others to explore practicability and economic aspects first. In fact, the results of early trials were outstandingly satisfactory, and reliability as good as the electronic specialists had predicted.

A major break-through was made in 1986, when Massey-Ferguson revealed a complete redesign of their 5-model 600 range with emergence of the 3000 Series. Many new features were subsequently further developed during completion of the Series and applied in slightly modified form where necessary in any cases where experience proved a need. The same features were adopted also in the additional 3600 and 3100 Series that followed. Basic designs included location of an improved engine well forward to provide a front-to-rear weight balance best suited to use of four-wheel-drive. This allowed easy side access to a new transmission system providing full synchromesh in 16 forward and reverse gears, with availability of ad-



Fig. 1.1 High powered tractor equipped for combined cultivation and drilling operation. The large-capacity front mounted seed hopper is balanced by a heavy Rau rototiller, large diameter packer roller and mounting for the Accord DF pneumatic drill at the rear. Beneath the seed hopper with its spiked wheel driving the seed metering mechanism is a

steerable packer roller which levels and lightly presses the strip between the tractor wheels. The metered seed is transferred to the mushroom at the rear and on to the coulters by a centrifugal fan powered by the tractor's external hydraulic system. The John Deere 4250 can lift all of the equipment for road transport. (Ferrag)

ditional press-button power-shift, and reverse shuttle where needed. A design feature in all three new Series was the use of a standard microprocessor to provide the option of automatic operation of all electro-hydraulic controls which can be more efficiently or more safely performed automatically than by the hand of a good human operator.

The Massey-Ferguson developments offered potential buyers a well thought out choice of options by including the basic automatic electronic transmission controls as standard in the less expensive 'Autotronic' models of each new Series. 'Top of range' models in each Series (labelled 'Datatronic') were equipped as standard with all of the 'Autotronic' automatic features plus extra instrumentation and automatic controls to provide desirable information plus control of work rates and work efficiency,

with printout of results where required. An alternative to the full 'Datatronic' package is the choice of only selected optional extras such as limitation of wheel slip to a level selected by the driver. A third complete package called 'Memotronic' added to the full 'Datatronic' specification provides for use of a cassette to record details of performance and work efficiency via the in-cab monitoring system, and later off-loading by a special playback unit direct to office computer.

Comparable advances by other leading manufacturers now make it worthwhile for progressive farmers to consider the advantages of the following features which are given more attention in Chapter 2 and the Appendix 2; and also the potential value of computerised management information.

Improved engines and overall designs

- Wide range of speeds, and ability to change gear immediately under load.
- Automatic disengagement of differential lock when implement is raised, and re-engagement when it is lowered.
- Options of electronic control of three-point linkage, with mix of draught and position control where desired.
- Choice of wheel-slip indication and automatic control of limit selected by driver.
- Data on work rates, areas covered and fuel used on hourly or daily basis.
- Automatic records of work rates, etc., and ease of transfer to farm office management computer.

Users are almost unanimous in confirming manufacturers' claims that automatic electronic controls can and do make a valuable contribution to drivers' ability to work long hours at peak periods without serious deterioration of alertness. Most report work satisfaction, and high efficiency of the whole tractor use operation.



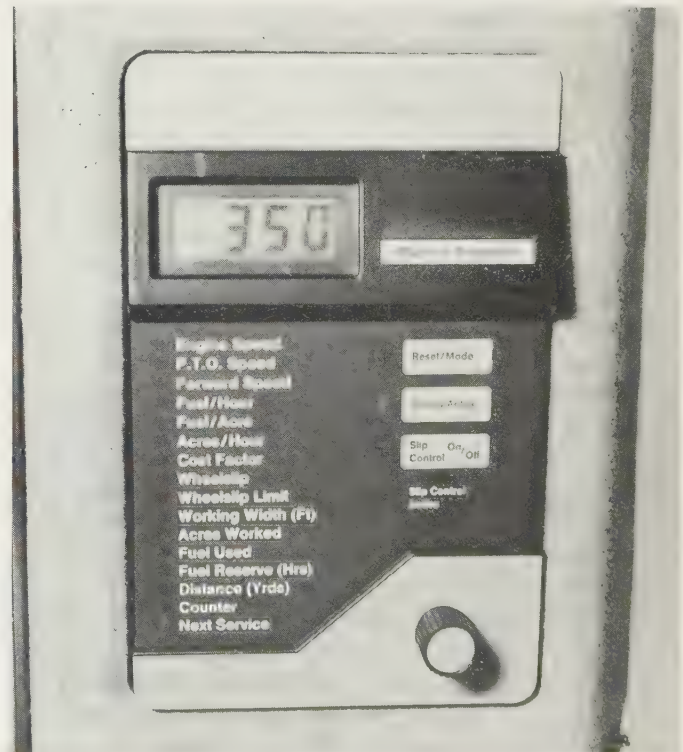
Fig. 1.2(a) above; (b) below

Use of front-mounted equipment

The robust design of the front ends of modern four-wheel-drive (4-W-D) tractors makes such vehicles well suited to use of front-mounted equipment. Interest in front mounting has been slow to develop in Britain and USA compared with Germany and Continental Europe,

Fig. 1.2(a) General view of driver's workplace in Massey-Ferguson 3600 'Datatronic' cab. The gear levers, electronic linkage console, gear levers and other microprocessor controls are handily grouped for right hand operation, and the Datatronic instrumentation display and controls are built into the rear pillar. The floor space is uncluttered, with suspended pedals, and the seat, steering column angle and steering wheel height are fully adjustable.

Fig. 1.2(b) Datatronic information which can be displayed by selecting appropriate button to left of the item required, and special controls on right for factors such as automatic wheel slip action.



but with the current steady increase of 4-W-D machines of 75 kW (100 hp) or over, it seems likely that an increasing number of UK farmers will wish to consider simultaneous use of equipment at both front and rear. The need will apply particularly to users of machines of about 150 kW who wish to complete cultivation and drilling in one bout across the field, and to large-scale silage-making operations.

Self-propelled machines

An aspect of development further considered in Chapter 2 is special-purpose vehicles as opposed to multi-purpose tractors. Examples include a wide range of rough-terrain mechanical handling vehicles which are tending to be used for most of the loading and handling work on farms of above-average size. Similarly, specialised vehicles for spraying and distributing fertiliser are increasingly used on large farms and for contract work, where needs include wheels for both low-ground-pressure work on soft, wet soils, and for high-clearance work in tall crops. For such needs hydrostatic transmission can be a good choice, allowing an infinitely variable forward speed and facilitating the design of a power frame providing an easy change from spraying to distributing. Specialised vehicles have obvious drawbacks in the case of seasonal machines such as combine harvesters, and many efforts have been made to develop self-propelled power units suitable for operating a range of mounted harvesting machines at different seasons. Examples include an American unit which powers a forage harvester, combine harvester or pick-up baler. In other countries somewhat similar units have been developed for powering a range of machines that includes potato and sugar-beet harvesters as well as machines for the hay and grain harvest. Developments in use of power drives of all kinds, and of hydraulic power in particular, will inevitably continue to change the conception of an all-purpose tractor based primarily on the use of draught power. When the main function is no longer primarily application of power through a drawbar or implement linkage at the rear, the basic reason for the 'conventional' shape disappears. Moreover, when the general use of safety cabs and remote implement controls no longer require the driver to be physically very close to the implement or machine, the position of the cab is no longer fixed over the rear axle. The value of a

front as well as a rear hydraulic lift linkage and pto has already been proved: forward-control cabs clearly have some advantages; and if a load platform can be incorporated it is found useful for many operations, especially those involving sowing, distributing, planting and spraying. Four-wheel-drive tractors with front and rear implement linkages have advantages for many combined operations. 'Reverse-drive' controls are in commercial production, and can offer advantages in some handling and harvesting operations. It is not practicable for low-priced 'all-purpose' tractors to be as technically efficient as specialist self-propelled machines for some complex harvesting operations or for handling unit loads, so the further development of specialised vehicles is certain. There is no sharp dividing line between some rough-terrain fork-lift vehicles and some all-purpose tractors, but specialist handling vehicles tend to provide for more hydraulic power, more safety when lifting heavy weights and better manoeuvrability than can be justified on a similar size of multi-purpose tractor.

Most of the improvements in multi-purpose tractors already outlined enable their makers to compete more effectively with some types of specialist self-propelled machines: but at the same time the successful manufacturers of self-propelled machines aim to cater for new uses for their specialist vehicles, such as an effective pick-up hitch for trailers, or adaptation of telescopic handling booms to work such as flail grass mowing and verge-trimming. Sound market research on a continuing basis is essential for continued competitiveness of companies on both sides of the specialist versus multi-purpose border areas.

Use of tractors in British farming

From 1906–10 the number of working horses on farms in England and Wales reached almost a million. By 1939, when there were 55 000 tractors, horse numbers had fallen to 549 000. A survey of tractor use in the Eastern Counties during the middle 1930s showed that tractors represented 42% and horses 45% of the total power available in tractors, horses and stationary engines, but that horses did 70% of the work and tractors only 26%.

By the end of the 1939–45 war the position had been transformed. Tractors had become much more versatile and horses of less importance, both in numbers and in

use. By the 1960s the contribution made by horses to work on farms in Britain had become insignificant, and numbers were no longer included in official statistics. Counts resumed in 1975 and 1979 (in England and Wales) showed 3000 and 4000 respectively: but such figures alone do not necessitate re-assessment of the contribution to farm work. Numbers of tractors (in England and Wales) rose to about 390 000 in the 1960s and remained at about the same level during the 1970s, in a period of continued reduction in numbers of farmers and workers and a steady increase in average power of new tractors. Official statistics show trends in numbers of tractors, by power group, used by farmers and contractors in all of the home countries. The following are for England only:

<i>pto power group (kW)</i>	<i>Dec. 1984</i>	<i>Dec. 1987</i>
Under 7 (including pedestrian controlled)	10 000	9 600
7–24.9	26 700	24 500
25–39.9	103 500	91 900
40–59.9	141 000	134 400
60–79.9	64 800	76 200
80–99.9	13 800	18 200
100–139.9	4 300	6 100
140 and over	1 500	1 200
Tracklayers	9 500	8 700
Total	375 100	370 800

The 40–100 kW (54–134 hp) and higher-powered groups are of increasing importance. Some of the reasons are to be found in parts of this book where attention is drawn to the saving of time and often improved technical performance where the tractor is used for a combination of operations rather than a single task in a complex chain of processes. The need to obtain high work rates is linked to the now small skilled labour force. The technical complexity of tractors and of their uses requires high standards of training from the main operators. Skilled operators come mainly from two whole-time groups: namely (1) full-time hired workers of all types, numbering 106 100 for England only in December 1989, the census figures having decreased by approximately 5000 annually over the previous five years; and (2) principal farmers, partners and directors, numbering 118 500 for England



Fig. 1.3 High powered 'conventional' four-wheel-drive tractor with reversible six-furrow plough at rear and three-furrow at front forms a well-balanced combination, emphasising increasing use of front linkages for a wide range of operations. (Ford New Holland)

only in December 1989, the figures having decreased by approximately 2500 annually over the previous five years. The trend towards higher-powered tractors and their use in 'combined' operations is likely to continue.

Little research has been carried out on economic aspects of tractor utilisation. Average annual use per tractor is less than 1000 hours. Increases in the power of tractors and in working capacities of machines are reducing the total hours of tractor use needed for particular farming systems, but to get good value from a new powerful tractor, use in the early years should be in the region of 1500 hours.

When tractor needs are being assessed, hours of use in the peak month is likely to be a more reliable guide than annual use. Investigations in Scotland and in southwestern England have shown that on large farms tractors may work over 140 hours per month, while on medium-sized farms 100 hours per month is rarely exceeded. On some mixed-cropping farms the peak may be March–April; on grass farms during silage or hay harvest; and on cereal farms September–October.

In considering the influence of the use of tractors on farming organisation the whole farming business must be

studied. Tractors have attained their present important position in British agriculture not merely on account of lower working costs, but also because of the benefits that arise from ability to do cultivations more thoroughly and in better season, with the production of more or better crops. Extra tractor work is frequently justified by a more intensive system of farming and a greater output.

Cost of tractor work

The cost of operating tractors varies from farm to farm and from district to district. Factors influencing costs, apart from the size and type of machine, include the number of days worked annually, the types of work performed and the care the tractor receives.

Farmers can calculate their own costs by keeping records of the amount of use; repairs and renewals; fuel, lubricating oil and grease; licence, insurance and housing. The main difficulty is to decide the method of reckoning depreciation. The simplest way is a very arbitrary one of assuming a life of, say, eight or ten years and spreading the capital cost equally over the period.

For most farmers there is a choice between (a) keeping the main tractor force fairly new by changing them regularly at an early age, at high depreciation cost, and (b) keeping them until they are nearly worn out. The latter policy can cost less, but usually results in higher repair costs and can result in some lack of reliability, with the possibility of adverse effects on farming operations. Policy adopted depends on levels of farming profits and cash flow, and partly on individual farmers' preferences and abilities. There can be no one rule on what is most economic, since differences in attitudes and needs of individual farmers are the essence of a viable second-hand tractor market. Tractors of exceptional kinds such as those of over 300 hp naturally have a limited second-hand value owing to problems in providing matching implements to use with them, as well as unsuitability for duties on small mixed farms.

Choice of a tractor

The best basis for choosing suitable tractors is experience, and practical trial in the conditions in which the machines are to work. Nevertheless, it is helpful to consider some

of the principles involved in choice and to mention factors that need to be studied.

Type of tractor

In most instances the tractor will need to be a 'multi-purpose' machine which can be applied to almost any kind of farm work, including ploughing, cultivations, sowing, row-crop work, harvesting, transport and stationary pto-work. This will apply particularly to small farms where one or two tractors are required to do everything. On larger farms sufficient kinds of particular work can warrant using special types, e.g. large four-wheel-drive tractors to cope with the autumn cultivation in good time and light types minimising soil compaction problems, but with a high power output for good performance with pto-drive arable machines or for work on forage harvesting. Market gardeners may require tractors specially adapted for work in vegetable crops, and such needs are briefly considered in Chapters 2 and 16, where the principal types of tractor available are described. Most modern medium-powered tractors incorporate such features as make them suitable for work in all common farm row crops. Standard wheel-track widths of 1.50 and 1.80 m (60 and 72 in.) meet most needs, but some adjustment is normally provided and is often needed for work such as ploughing.

Tractor sizes, and standardisation

The classification of tractor sizes is well indicated by recommended ranges for three-point-linkage categories. These have changed with extensions of the range necessitated by the introduction of increasingly powerful tractors. The following figures based on Society of Automotive Engineers (SAE) recommendations indicate current (1990) sizes: ISO/730 uses similar figures.

Category	Max. drawbar power range (kW)
1	15–35
2	30–75
3	60–168
4	135–300

Category 2 is most widely used, but category 1 is used for many implements designed for use with small to medium tractors. Fortunately, many mounted implements and

machines are now designed for use with either category 1 or 2 tractors, and this is a point to note in selecting equipment.

The power needed for ploughing and other cultivations varies greatly according to the nature and condition of the land. The 'ploughing resistance' of various types of soil may be indicated by a figure which, when multiplied by the total sectional area of the furrow slices, gives the drawbar pull needed. Ploughing resistances range from about 5 lbf/in² (34.5 kN/m²) for very light blowing sand to over 15 lbf/in² (103.4 kN/m²) for heavy clay, an average figure for medium loam being about 10 lbf/in² (68.95 kN/m²) of furrow section. Drawbar pulls and power required can be considerably increased in compacted dry soils, especially at speeds above about 4 mph.

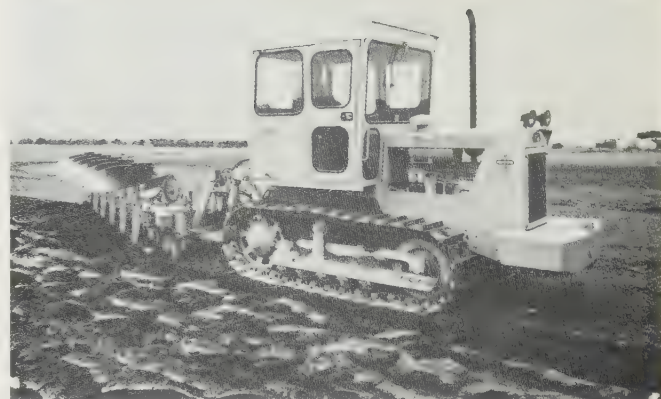


Fig. 1.5 The 123 BHP tracklayer with single-lever two-stage power operated controlled differential steering, is here seen with six-furrow mounted plough. (*Track-Marshall/Dowdeswell*)



Fig. 1.4 Graph showing maximum torque to maximum speed mile/h for tractor of recent design (MF 3080) with 16-speed gearbox on 16.9/14-38 tyres. (*Massey-Ferguson*)

Cultivation performance is not the only factor determining the choice of tractor power, especially on larger farms. Several specialised machines, especially those dealing with the harvesting of forage, require considerable power at the pto. Their output is, in fact, often directly related to the tractor power available. With the need for greater output per man, high power at the pto is becoming an increasingly important criterion in deciding the size or type of tractor to be bought. Where a large tractor can be given a full load there may be a considerable saving of labour cost by using it — a fact which may often be taken advantage of on large farms and by contractors.

Tractors in developed countries have steadily become more versatile, safer, and more efficient; and development of use of automatic controls is certain to continue.

Advances in tractor engines

Some technical aspects of factors involved in advanced engine designs are mentioned under tractor testing and in Appendices 1 and 3; but it is appropriate here to comment on broad economic factors which enable the leading tractor manufacturers to satisfy the economic needs of farmers in respect of justification for extra capital cost in changing to substantially improved designs. It has become common practice when a new tractor engine is developed to take advantage of a wide range of automatic electronic controls

which can achieve more precise regulation of timing of both the beginning and end of fuel injection, and, in conjunction with new piston and cylinder head designs, to create a smoother fuel ignition process that is appreciably quieter and more efficient in specific fuel consumption than can be attained by earlier designs. A complete redesign of the tractor can also permit the development of a new engine series covering a wide range of power needs using standardised components throughout.

An example is the John Deere 55 five-model series ranging from 94 to 168 kW (128 to 228 hp) using the same six-cylinder 7.6 litre capacity engine with 15-speed hydraulically operated power-shift gearbox without use of a conventional clutch; and having a mechanised four-wheel-drive with automatic front diff-lock control. The torque reserve remains constant at up to 38% between 1700 and 1200 rpm engine speed.

A feature of recent Massey-Ferguson developments is the 3100 Series based on use of a new Perkins engine incorporating 'Quadram' pistons, providing a central swirl chamber with four high-turbulence pockets claimed to achieve quicker and more thorough mixing of air and fuel, and resulting in increase of both power and torque by 14%; torque reserve increased by 18%; and specific fuel economy improved by 8% to 9%. A bonus of importance was a reduction of engine noise at the driver's ear by 3 dBA, i.e. a very substantial percentage reduction. The gears in this case provide a 4×4 16-speed format with shuttle reverse on the lowest four, and provision for a top speed of 40 km/h.

Deutz-Fahr, working on a range of air-cooled engines widely used on tractors and self-propelled vehicles have introduced the Agrostar DX6 Series of four models with four-wheel-drive, a swept engine volume of 6.128 litres and power ranging from 102 to 143 DIN HP; and DX4 models in addition. A torque reserve of 26% is claimed and a new transmission offers up to 48 forward gears including a 40 km/h road speed. An outstanding feature in the list of attributes is a quite exceptional improvement in noise at the driver's ear. An early official OECD test on the DX4 model 71A produced a figure of 72.5 dBA, which is below half that of some fairly modern OECD-tested tractors.

In addition to the manufacturers mentioned above as examples of a trend towards use of improved engines of the same swept volume for a range of tractor powers, a *Power Farming Tractor Buyers' Guide* for July 1990 shows

that a considerable majority of the world's leading tractor manufacturers already employ similar production policies.

Control of transmissions

The steady increase in tractor powers already mentioned is clearly related to the continuing decrease in numbers of full-time workers available. Improved designs help to ensure that the more powerful and efficient engines are matched by transmissions, linkages, controls and trained drivers able to make work outputs do more than keep pace with the increased complexity and capital costs of the new models. Fig. A2.4 (Appendix 2) shows an up-to-date example of a fully synchromesh 16-speed gearbox, and Fig. 1.4 shows in graphical form the range of speed performances at maximum speed and maximum torque for each gear. The quality of the hydraulically powered gear change operations is comparable with driving a modern car; and in addition a press-button hydraulically operated speed shift can provide an immediate increase in pulling power of 26%, making it easy to continue work at a slower speed through the toughest conditions.

Following the David Brown Hydrashift development many years ago, the John Deere 50 Series set a standard for high-powered tractors with a 15-speed gear box having concentric shafts with hydraulically controlled clutches and braked ring gears. More modern designs tend to favour simpler production engineering based on multiple use of simple power-shift mechanisms. A European-made range by Case-International with transmission described by the manufacturer as semi-power-shift allows the driver to make on-the-move clutchless gear changes with each of four ranges provided. Low-pressure hydraulic oil releases and engages hydraulic clutch packs within the total 16 forward, 12 reverse speed system. Operation is electronically controlled by a microprocessor which releases pressure on the automatic clutch being disengaged and pressurises the brake being engaged. Power shuttle gives forward/reverse shift in the lower three of the four gear ranges. The reverse speeds are 20% higher than those of the forward gears paired with them. A torque limiting device on the flywheel protects the drive train from overloading.

Four-wheel-drive, when needed, is engaged by electro-hydraulic rocker shift. If hydraulic pressure fails, front axle drive is automatically engaged. The design is indicative of logical choice in a medium-high power range introduced for the 1990s. At lower powers (e.g. 38–45 kW),

where price is relatively more important, another basic synchromesh power shift gear box with eight forward speeds relies on a clutch-less epicyclic change to reduce each of the eight ratios by 22%, thereby providing 16 forward speeds at regular spacing. For safe operation the shuttle reverse lever has a spring loaded neutral between forward and reverse to stop the driver moving straight through accidentally (e.g. Massey-Ferguson 300 Series). These examples of transmission developments are illustrative of general trends, formerly restricted by manufacturers to top-of-the-range sizes, but likely increasingly to influence choice in the popular ranges.

Electronic monitoring and control

The efficiency and reliability of electronic monitoring and control equipment have already been sufficiently proved in commercial field work to make it certain that leading tractor manufacturers will extend the use of automatic electronic tractor transmission controls to the medium powered and popular ranges. Where direct action by automatic control is practicable, as with draught and depth of tillage equipment, or control of wheel slip, there is considerable advantage in being able to free the driver from unnecessary actions, so enabling him to concentrate on driving to avoid any visible troubles.

The provision made by some leading tractor manufacturers for making automatic records of field performance when operating several types of machines should quite soon lead to the accumulation of valuable management data on field inputs, work rates, areas covered and fuel consumptions. With regular collection of such data the information is likely to become increasingly reliable as a basis for future management targets.

Wheel and track equipment

For general farm work, where the medium-powered tractor is to be regularly used for transport as well as for all kinds of field work, pneumatic-tyred wheels are now an automatic choice.

The development of tracklayers of advanced design equipped with rubber tracks has created an interesting technical situation which is briefly examined in Chapter 2. The impact on farming generally may be restricted in practice for a time by capital cost considerations. For



Fig. 1.6 The Deutz-Fahr Agrostar range comprising five models from 88 to 143 DIN hp all with newly designed engines and four-wheel-drive transmission designs resulting in substantially increased engine powers with torque rise up to 26% and an official OECD noise test result of only 72.5 dBA at the driver's ear. The fully synchromesh two-lever transmissions provide up to 48 forward and 12 reverse speeds. (Watveare Deutz-Fahr DX 6.11)

seed-bed preparation work simple devices such as cage wheels on a reasonably light four-wheel-drive can often be worth study. One of the main advantages of a tracklayer is its ability on sensitive wet soils to avoid serious damage to soil structure by running on top of the land when ploughing late in autumn or early in spring. It is claimed that the steel reinforced rubber tracks of the Caterpillar Challenger 65 which have a ground contact area of 3.35 m^2 provide improved flotation compared with comparable machines fitted with conventional steel tracks.

Tractor testing

Regular tractor testing dates back to 1920, when a scheme for the compulsory testing of all types of tractors marketed in the State of Nebraska, USA, was inaugurated. The Nebraska tests determine the rated powers of tractors according to a Standard Farm Tractor Rating Code, drawn up by the American Society of Agricultural Engineers (ASAE) and the Society of Automotive Engineers (SAE). Without entering into the technicalities of how the maxi-

imum powers are measured, reference may be made to a useful rule to the effect that the *rated belt horse-power* must not exceed 85% of the maximum belt horse-power developed continuously on test, and that the *drawbar rating* must not exceed 75% of the maximum drawbar horse-power.

There are many good reasons for rating tractors below the maximum powers developed on test. For example, the tractors are tested for drawbar power on tracks which are level, straight and have good surfaces for adhesion; and the maximum load is gradually applied by electrical and other special devices. Working conditions in the field are always much less favourable, and tractors cannot generally develop their maximum test horse-powers when in practical use.

With modern tractor engines, power depends to a large extent on engine speed. Under the widely used OECD Test Code the manufacturer nominates the *rated engine speed* which is intended to be employed for continuous operation, and some of the tests made are based on use of this rated speed (see also Appendix 3).

In Britain, tractor testing is not compulsory, but tractor manufacturers make use of the testing facilities provided by Silsoe Research Institute.

Use is made of a standard code for the official testing of agricultural tractors developed by the Organisation for Economic Co-operation and Development (OECD). The International Organisation for Standardisation (ISO) has developed a range of test codes that aim to cover all tractor-testing needs world wide. Reports of tests by any of the authorities in the OECD co-operating countries are directly comparable, and this avoids duplication of testing. The OECD test code provides for a number of compulsory tests. Power is measured at the pto with the tractor stationary, at various engine speeds including rated engine speed and the standard pto speeds of 540 and 1000 rpm. Bare engine tests (in the installed condition) and tests on the belt pulley may be included at the request of the manufacturer. The drawbar tests of pneumatic tyred tractors are carried out on dry, level tarmac, both with and without ballast. These drawbar tests are somewhat artificial, but provide maximum performances which are comparable wherever the test is carried out. The development of tests of drawbar power by means of tread-mills of various kinds is proceeding, and it is possible that this even more artificial method will ultimately displace the use of a tarmac surface.

Tracklayers and steel-wheeled tractors are tested on dry, level, mown or grazed grassland on heavy clay.

During the various measurements of tractor power both at the pto and at the drawbar, the corresponding fuel consumption is also measured. The relationship between power output and fuel consumption (specific fuel consumption) is calculated and allows a direct comparison of efficiencies of the different tractors tested to be made. In addition, tests and performance measurements are made of the hydraulic lift, brakes and turning circle. Increased attention to operator comfort and the introduction of regulations have resulted in the measurements of noise heard both by the driver and bystander being included in the OECD test code.

The results are presented partly in the form of graphs. These are sometimes not understood by interested readers, so a simple explanation of the torque/speed, power/speed and drawbar power/pull curves is given in Appendix 3.

Interpretation of tractor test results

The reader who wishes to understand test reports should first appreciate the significance of the simple relationship between drawbar pull, tractor speed and drawbar power, and should also understand the torque/speed, power/speed and power/pull graphs (see Appendix 3). Maximum drawbar pulls on a test track are usually limited not by the power of the engine, but by wheel slip, and they can be greatly increased at low speeds merely by adding weight to the tractor. Within limits, with pneumatic tyres on firm ground the addition of 454 kg (1000 lb) ballast to the rear wheels will usually increase the maximum drawbar pull by about 500 lbf (2.224 kN). It is, therefore, necessary to note how much weight has been added, and whether the addition of such weight would be practicable in farm conditions. It must be realised that it would be possible for a tractor fitted with wheels quite unsuitable for normal farm work to put up an excellent drawbar performance in the Nebraska test or the British Standard, ISO or OECD test. It is always useful to study the results of ploughing and other agricultural tests when these are available.

Increasing the maximum drawbar pull by adding extra weight does not necessarily increase the maximum drawbar power developed by a tractor. In the case of pneumatic-tyred tractors, as is shown later, the maximum drawbar power is attained at fairly high speeds and low drawbar



Fig. 1.7 The 190 hp tractor designed primarily for heavy drawbar work is the highest-powered of a range of five which use variants of the same six-cylinder diesel engine. Utilisation of tractors mainly for draught purposes has tended in the second half of the 20th century to be associated mainly with large-scale cereal-growing in areas such as the prairies of North America and the Steppes of Russia in association with fairly shallow disc cultivation and use of discer-seeders. The twin rear wheels with all-wheel-drive and heavy front weights are needed to secure an economic performance using the deep-working cultivator seen here. (*John Deere 4755*)

pulls: the limiting factor at these higher speeds is engine power and not wheel slip. The addition of extra weight at these higher speeds will usually, in fact, slightly reduce the maximum drawbar power.

Tractor manufacturers usually specify a 'rated' engine speed for normal drawbar work. In some cases the rated speed is appreciably lower than that at which full power is produced. For example, rated speed may be 1500 rpm in a tractor which produces maximum power at 2000 rpm. Standard pto speed is usually obtained at somewhere near the rated engine speed. This means that where heavy pto work such as driving forage harvesters has to



Fig. 1.8 The Deutz-Fahr DX 4.57 shown with Accord type front pick-up hitch has an engine of 66 kW (90 hp) and general design features that make it well suited to combined front-and-rear grass harvesting work, front handling operations and fairly high road speeds in many European countries.

be done at approximately standard pto speed, the power that can be applied at this speed may be well below the tractor's maximum power. The standard pto test must be carried out at the standard speed (among others), and this requirement should help to ensure that the user at least knows what power at the pto can be expected.

Economic operation: loading

So long as a tractor is in use, even though the work is very light, labour has to be employed to drive it and expense is incurred on depreciation, repairs, lubricating oil and fuel. Apart from fuel cost, none of these items is greatly influenced by the load. Thus, labour is a constant charge per hour and it has also been found that provided there is no overloading of the tractor, depreciation and repairs are very little higher in an engine working at three-quarters load than in one working at half load, assuming that each works the same number of hours per year. The labour and overhead charges therefore represent an almost constant charge per hour, regardless of how much power is developed; and on average, these constant charges represent about three-quarters of the total cost of running the tractor at full load. If the tractor is worked at half load or less, the labour and overhead charges account for more than three-quarters of the total cost, and the only hourly saving of any importance is the reduction in the amount of fuel used. This is not a real saving if the work rate is correspondingly low. It is, therefore, important for economical working to provide the tractor with a fairly heavy load whenever practicable.

The tractor engine is normally fitted with a governor to ensure that the engine maintains a selected speed. A gearbox provides various definite forward speed ratios, and assuming that the governor keeps the engine speed constant and that there are no complications due to slippage, the tractor has definite forward speeds. ISO 3965 (= BS 5510) specifies test and calculation methods for determining maximum design travel speed.

For each gear the tractor has a fairly definite optimum drawbar pull, and this optimum is generally about 75% of the maximum drawbar pull at the speed. The object should therefore be to provide implements which require drawbar pulls approximating to this optimum. In work such as ploughing it is particularly easy to adjust load if a variable-width plough is used; and with many modern

ploughs it is not difficult and can be worthwhile to add or remove a complete plough body.

There are times when it is impossible to load a tractor adequately, but at other times it is possible to increase efficiency greatly by either adding to the load or working in a higher gear. A practical method commonly employed to provide a full load and speed up the work is to hitch implements in tandem. There are often savings in both time and money if operations such as discing and harrowing, drilling and harrowing, rolling and harrowing, etc., are carried out in one journey across the field. There are, of course, operations where it is impracticable to increase either the width of work or the speed, or to hitch implements in tandem. In such circumstances the best solution will be to run the tractor in a higher gear, with the engine throttled down. Where a two-speed pto is available and the driven machine needs only low power at 540 rpm pto speed, it may be both most economic and comfortable for the operator to use the 1000 rpm pto and to cut down the engine rpm to almost half the rated speed. Where this is done, care must be taken to avoid use of the high engine speeds, since this can result in dangerously high speeds in the driven equipment.

Wheel slip

Slipping of a tractor's drive wheels always wastes power and fuel, and with pneumatic tyres this wastage may be serious, even if the wheels do not spin. A simple method of determining wheel slip when a tractor is working is to make a mark on the tractor wheel and then measure the distance the tractor moves forward in, say, ten revolutions of the wheel, first under load, and then on the same surface with no load.

The percentage slip will be:

$$\frac{\left[\begin{array}{c} \text{Distance travelled} \\ \text{without load} \end{array} \right] - \left[\begin{array}{c} \text{Distance travelled} \\ \text{when working} \end{array} \right]}{\text{Distance travelled without load}} \times 100$$

The amount of slip revealed by such a test is often surprising. Fifteen per cent slip on pneumatic tyres is hardly noticeable, and on heavy draught work this level often has to be accepted. Slip can never be entirely eliminated, but can sometimes be minimised by lightening the load and working in a higher gear, while at other times it may be remedied by adding weight, fitting strakes

or fitting alternative types of wheel or track equipment. Choice of automatic slip control settings is a valuable standard feature of the Massey-Ferguson Datatronic package and also of the inexpensive Tractor Performance Monitor packages offered by RDS for all suitable tractors and by Ford for use in its fully tractor instrumented Super Q-Cabs.

Operating speeds

Because of the limitations imposed by wheel slip at high drawbar pulls, modern pneumatic-tyred tractors can only exert their maximum drawbar powers at moderately high speeds. But the ability of pneumatic-tyred tractors to produce their highest draught power output at a fairly high forward speed is not the only consideration: results of many trials show that on tillage work, draught often increases substantially with forward speed. For example, increase of the speed of ploughing from 2.5 to 4 mph (4 to 6.4 km/h) increases the draught by 10% to 20%.

The increased draught is sometimes justified by better work (due to more pulverisation of the soil). There are, however, some jobs such as spraying, hoeing, combining, etc., which cannot be performed at above a certain critical speed without causing very poor work.

For ploughing, special high-speed bodies are required for work above 5–10 mph (8–16 km/h). Normal plough bodies simply will not stay in the ground at high speeds.

A practical objection to the use of very low speeds is that they necessitate high drawbar pulls to provide a full load. It may be inconvenient to provide large enough implements, and in any case, under ordinary field conditions the tractor may be unable to exert very high drawbar pulls owing to adhesion difficulties. For heavy draught work at normal speeds modern tractors need about 100 kg of weight on the drive wheels per kW of power. This kind of power:weight ratio is more easily available in four-wheel-drive tractors than in rear-wheel-drive. On the other hand, unnecessary weight in a tractor that is used mainly on pto work is undesirable: it adds to



Fig. 1.9 The eight-wheel-drive articulated tractor of 300 hp is seen ploughing with Dowdeswell 10-furrow reversible plough in UK conditions. (*Ford-New Holland Versatile*)



Fig. 1.10 Developments in electro-hydraulic controls have greatly improved the speed and safety of hitching heavy implements. The external hydraulic control buttons enable the driver to locate height of lift arms accurately from a safe position. (Massey-Ferguson 'Datatronic')

rolling resistance and wastes power to overcome it at a rate of about 2 kW per extra tonne. So ballast should be easily removed when necessary.

Most modern rear-wheel-drive tractors have to be a compromise in specification because of their all-purpose needs. Their standard tyres are often not big enough and their ballasted weight not heavy enough to secure highest efficiency in heavy draught work. Four-wheel-drive versions can provide the extra weight as well as the extra drive wheels, and experiments have shown that in adverse conditions the fuel savings resulting from reduced slip and a faster work rate can be up to about 30% for a given job. Nevertheless, the standard two-wheel-drive version can be more efficient as well as cheaper for many kinds of work not requiring a high drawbar pull in adverse soil conditions.

Where high drawbar pulls are required from two-wheel-drive tractors the fitting of larger or dual tyres can usefully be considered. For example, a 60 kW tractor might be

fitted with 20.8–34 singles or 16.9–34 dual wheels. Ballast can then be added to bring weight on the drive wheels to 100 kg/kW, including the weight of a mounted implement. A heavy rear axle weight is undesirable when the tractor is used on damp seedbeds or on growing crops. It is often difficult to utilise fully the power of large wheeled tractors which may have been purchased with the autumn cultivations in mind. When it comes to relatively low-draught work such as harrowing and spring drilling, the conventional implements are not wide enough to utilise the available drawbar power. There is a practical limit to increases in either forward speed or width of the implement. Under these circumstances farmers might well consider the use of multiple hitches to pull two corn drills or one drill plus a set of harrows and rolls at the same time. This not only saves on the number of operations but helps to reduce the possible ill-effects of too many wheelings on the seedbed. At the same time it more effectively uses the tractor power available. The usual design of multiple hitch provides a braced framework carried on castor wheels. Individual implements are hitched by means of adjustable brackets to the rear bar of the frame, sometimes by drawbars of differing lengths to allow a slight overlap of the working parts. In other cases implements may be specially designed to hitch side-by-side, rub buffers being provided to avoid fouling during turns. Where very wide hitches are used, a pair of inner wheels may be non-castoring, and the outer sections with castor wheels may be arranged to fold for transport, the lifting being by hydraulic cylinders.

Road traffic regulations

UK road traffic regulations make it illegal for conventional unsprung tractors not equipped with lorry type air brakes and suspensions to exceed 20 mph (32 km/h) on the highway; but some British and European tractor manufacturers, taking account of users' wishes in other European countries to use gearboxes providing up to 25 mph (40 km/h), have made such speeds possible: it is reasonably argued that a careful user can travel at the UK legal speed limit by restricting engine speed, and that this can be relied on to reduce engine wear and tear, and reduce noise levels. Provision of the higher-speed gearbox may be accompanied by fitting front-wheel mudguards and providing extra forward gear ratios.

Requirements for travel on UK roads at above 20 mph include fitting truck-style vacuum brakes and back-up systems and can add considerably to cost. German MB-Tracs and Unimogs with suitable high-speed trailers have legal speeds valuable for uses such as long-distance movement of big bales from field to farm store.

Engine speed

The modern tendency is to supplement the speed range provided by the gearbox by means of a good, flexible governor control. The governor is made capable of adjustment to give, in normal working conditions, over 50% more or less than the standard governed engine speed, so that a speed range of, say, 2 mph to 13 mph (3.2–21 km/h) is extended by means of the governor control to a range of 1 mph to 20 mph (1.6–32 km/h).

Intelligent use of the gears and governor control can result in appreciable fuel economy, as well as saving of time. Most tractor engines show lowest *specific* fuel consumption at about 75% of maximum power and engine speed. The best source of figures for comparison of makes is OECD pto tests, which include losses of power in driving accessories for power steering, hydraulic gearshift, etc. Use of an over-powered tractor on light pto work almost inevitably wastes fuel owing to the limitations imposed by the need to maintain a given pto speed, combined with the machine's forward speed limitations.

Occasionally there is a choice of more than two gears and engine speeds. Tests confirm that for fuel economy it always pays to choose a high gear and low engine speed whenever this is practicable. It is, of course, only at light or moderate drawbar pulls that there is any choice, but so much of a tractor's working time is spent on light work that this is a point of some importance. Engine speed should not, of course, be reduced to the point at which the engine fails to respond easily to a demand for increased power or speed.

Maintenance and the tractor driver

All manufacturers provide a handbook giving detailed instructions on such matters as adjustments, greasing, changing lubricating oil, correct grade of oil for various parts of the tractor, and so on. The handbook is probably the most important part of the tractor's tool-kit, and

the instructions contained in it should be carried out as thoroughly as possible.

The driver is assisted and encouraged to attend regularly to maintenance if he is provided with a log-book in which changes of lubricating oil and dates of the various other types of servicing are regularly recorded. Such a log-book, if properly kept, permits a check on fuel and oil consumption, and makes it easy to see at any time whether the tractor is due to be serviced or not. The electronic information sensing, display and storage equipment provided on some modern tractors can yield substantial assistance to drivers and managers in carrying out needed routine maintenance procedures. Tractors are rarely serviced as frequently as recommended by the manufacturer and it is a tribute to the reliability of this important item of farming equipment that major troubles resulting from lack of maintenance are rare. No doubt in framing routine maintenance recommendations manufacturers take into account the worst conditions their product is likely to meet. Nevertheless, the basic essentials of regular lubrication and fuel and oil filter changes should be adhered to. Apart from an initial tightening of the cylinder head bolts and adjustment of the tappets at the end of the running-in period, there should generally be no reason for disturbing the engine so long as performance is satisfactory. The complexity of the hydraulic services of a modern tractor is such that most operators' manuals devote a considerable proportion of their space to describing their operation and use. This information should be used by the driver as a reminder of the detailed knowledge and skill that he should seek to acquire, with the help of the dealer from whom the tractor was purchased.

Safety precautions

Farmers and tractor drivers should never forget that limbs and lives may be endangered unless precautions are taken in handling power-driven machinery. Causes of accidents include carelessness in hitching to implements, failure to fit proper shields over power drive shafts, clearing blockages with power drive engaged, and overturning.

There are always potential dangers in manual hitching of tractor-operated equipment, and these are accentuated if an unaided driver ignores basic driving rules (e.g. regarding driver's position when operating controls), or if he is incompetent when assisted by someone who stands be-

tween tractor and equipment. Dangers can be reduced or sometimes eliminated by improved designs: for example, a reliable automatic pick-up hitch makes it possible for equipment to be hitched up safely by an unaided driver, who often need not leave his safety cab. Unfortunately, safety cabs alone tend to make hitching more difficult, and dangers are increased if equipment is badly parked on an unsuitable surface.

Power drives are now the subject of stringent safety regulations and must be properly guarded. The square shafts and universal joints, if not properly covered, readily catch up any loose clothing; and if this happens, the operator is lucky indeed if it is only his clothing that suffers. All power drives must be effectively shielded, and tractor drivers and all other workers who have to go near machinery in motion should avoid wearing loose clothing. Trying to clear blocked harvesting machines with the power drive operating can easily trap a limb, and lead to loss of limb or of life.

Driving on slopes

A high centre of gravity, narrow wheel track width and centrifugal forces caused by sharp turns increase the overturning risk for accident-prone vehicles such as high-clearance sprayers and tractors or specialist rough-terrain vehicles with raised loads. In addition, there are unexpected risks, such as an upper wheel striking a boulder as a lower one drops in a depression, which can affect all vehicles and can only be guarded against by the operator's care and skill. Many working accidents due to slopes, however, occur on smooth firm grassland. The coefficient of friction between the rubber of tractor and vehicle wheels and short grass is low, and the only conditions on a steep slope in which a typical rear-wheel-drive tractor can be fully controlled are where the tread of the drive wheels can secure some penetration into the soil. A rear-wheel-drive tractor can safely be driven up a slope that is dangerous to drive down, partly because there is effective weight transfer to the driven and braked wheels only when going uphill. When drive-wheel lugs do not penetrate, the transition from what appears to be safe braking to an uncontrollable slide is sudden. The greater the speed, the greater the chance of loss of control and eventual overturning. Unbraked machines behind tractors – e.g. a forage harvester and silage trailer, can precipitate a

slide on quite gentle slopes, especially on the point of turning. Work can sometimes be effectively carried out across a slope that cannot safely be worked downhill: in such conditions the widest possible track widths for both tractors and trailed vehicles should be used. Four-wheel-drive tractors with positive drive to all wheels are safer on slopes than comparable rear-wheel-drive models, especially when travelling downhill. Development work at the Scottish Centre of Agricultural Engineering shows that safe operation of conventional two-wheel-drive tractors on slopes can be greatly improved by fitting spiked extension wheels to run at a wider track width, outside the pneumatic tyres. The lugs provide a positive grip, and the increased width is an added advantage on side slopes. A cab-mounted mercury switch can be used to provide an audible alarm three seconds after an indicated slope angle of 12° is reached. This can serve as a reminder to engage four-wheel-drive immediately if it is available.

Safety regulations and marketing directives

There are several government regulations which are designed to avoid or mitigate the consequences of serious accidents and/or to protect the health and welfare of drivers. No attempt can be made here to detail the legislation concerning tractors, or even to mention some regulations of general application; a few of the more important tractor regulations are listed in the references.

To protect drivers against the most serious consequences of overturning, the 1967 Tractor Safety (Cab) Regulations require all new tractors save a few special types to be fitted with a safety cab which has undergone a specified standard test and has been granted an official certificate of approval. The original regulation dealt solely with mechanical protection, but the Tractor Safety Cabs (Amendment) Regulations, 1973, require that the *maximum* noise at the driver's ear as measured by the specified test code for new tractors is 90 dBA. From 1977 no employed person has been permitted to drive a tractor without a safety cab. Some cabs incorporate easy lift-off features for the benefit of users who are able to obtain exemption from the general regulations for particular purposes such as orchard work. In a typical example, the upper part of the cab may be lifted off after removal of doors and fixing bolts, and disconnecting electrical leads.

'Type Approval' tests are related to such regulations

and devised by the EC with a view to maintaining standards when equipment is exported, usually within the European Common Market. The tests are paid for by the exporting manufacturers and usually carried out by an official test station of the exporting manufacturer's country. The tests are concerned particularly with such matters as lighting, light signals, braking and other controls including maximum road speed.

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Tractors: Constructional Features

Principal types of tractor

This chapter deals with some of the main constructional features of tractors and power frames applicable to common agricultural and commercial horticultural needs. The increasing variety of powered vehicles designed to improve performance on specialised operations has been noted in Chapter 1. Established tractor manufacturers design new multi-purpose tractors with a careful selection of improved facilities; while specialist vehicle manufacturers often improve multi-purpose facilities by adding standard tractor features such as a hydraulic pick-up trailer hitch. Size can be less than 20 hp to over 300 hp, so terms such as small, medium or large now have little meaning used alone. Some features such as engines, transmissions, wheels, steering, braking, hydraulic power application, lift linkages and controls are considered in turn. A few basic aspects such as engines are covered mainly in the Appendices, and more specialist vehicles are discussed also in the chapters on spraying, harvesting and materials handling.

Increased use of high-powered tractors necessitates bigger and heavier equipment, and leads to important problems of matching and balance between the two. With ploughing, a large implement needs to be long; and when the number of furrows exceeds about five, the relative merits of a very long semi-mounted plough need to be compared with fully mounted smaller implements at both front and rear. More sophisticated electrohydraulic controls with a measure of automation are a factor to be considered when tractor or power-frame operation is being compared with fully specialist self-powered machines on work such as harvesting.

The availability of effective multi-purpose front implement linkages and ptos makes it certain that this feature will be increasingly demanded. Designs with seat

and controls on a turntable providing 180° rotation enhance multi-purpose capability and enable tractors to compete with specialist self-powered machines for work such as forage harvesting and heavy-duty loading. Increasing sophistication of electrohydraulic control systems, with microprocessor involvement where economic, can add appreciably to initial cost and necessitate some specialist operator training; but benefits can be substantial and such trends are likely to be further developed wherever advanced production systems are practised. Electronic sensing and control permits more rapid action of hydraulic draught control systems, and provides a good basis for use of performance monitors and automatic controls.

Track widths and crop clearance

A reasonably high clearance and easy alteration of wheel track width setting are essential features where several types of row crops are to be worked. Ease of wheel changing is also necessary where both high clearance and low-ground-pressure work must be carried out by one vehicle. There is no conflict and farmers accept frequent wheel changes provided that the job can be done easily and safely. A track width of 1.83 m (6 ft) is increasingly used for work in potatoes. Commonly used metric track widths of 1.5 m or 1.8 m for tractors of about 40–60 kW allow for row-crop spacings as follows:

Tractor track width (m)	Row-crop spacings (mm)				
	750	500	375	250	
1.50					
1.80	900	600	450	300	

Steering gear

Small tractors employ mechanisms that are fundamentally similar to those found on cars and trucks, with a steering box, drop arm and drag link, which are connected to the swivel pins, track arms and track rod of the front axle unit. A typical layout is shown in Fig. 2.1. Most large tractors need either power-assisted or full hydrostatic steering. On smaller tractors power-assisted steering is often available as an option. In one example, a special hydraulic pump is directly driven from the engine crankshaft and supplies oil at 2.5 gal (11.4 l) per min and a pressure of 400 psi (27.6 bar). The oil powers a double-acting ram which incorporates a shuttle valve assembly to direct the flow of oil as required. A slight movement of the steering wheel, operating in the usual way through a drag link, moves the shuttle valve assembly to provide the required motion. Provision must be made for power-assisted systems to be manually operated if the power system fails.

With fully hydrostatic systems there is no mechanical linkage between the steering wheel and the steered wheels. Such systems allow freedom in location of controls and can give high levels of operator comfort. Regulations require provision for residual steering in the absence of the main hydraulic power source.

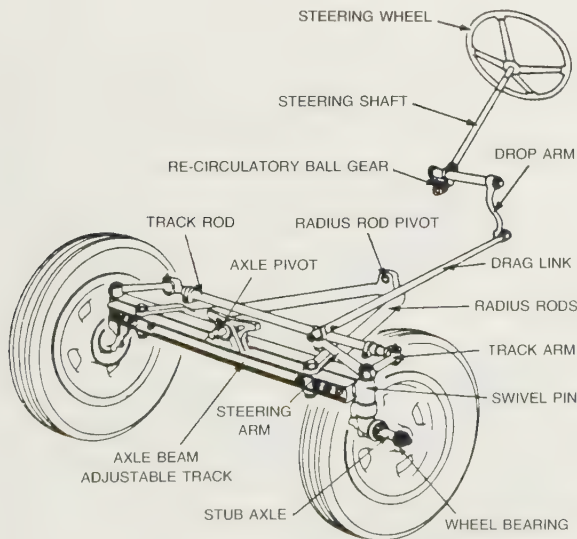


Fig. 2.1 Orthodox steering gear for four-wheeled tractor, with extensible front axle beam and track rods.

Steering powerful modern four-wheel-drive tractors requires an entirely different approach. As with developments by many other leading manufacturers worldwide, modern ranges introduced by the Case-IH Organisation are based on completely new engines, transmissions, and computer-based instrumentation and controls. The medium powered (90–110 hp) MAXXUMS are of conventional style and almost invariably four-wheel drive. Hydrostatic power steering is standard, and independent checks have shown that at normal track width (72 in) less than five easy turns of the steering wheel provides lock-to-lock turning on a minimum radius of about 4.65 m (15.3 ft). A higher-powered range (Fig. 2.2), the Magnums (114–181 kW) (155–230 hp) with four-wheel-drive standard, provides similar good handling at high power levels. In both ranges, press-button or finger-tip electronic control levers permit precise and fast initiation of operator controls and, where required, of computer-initiated automatic controls such as engagement or disengagement of front-axle differential lock.

Ease of adjustment of the wheel *track widths* on a row-crop tractor is an important feature, for it is easy with some tractors to waste half a day on this job. Where only open-field work has to be considered, rear wheels with a sliding wheel hub fixed to the axle shaft by means of an easily loosened clamp is one of the easiest to adjust. The



Fig. 2.2 205 hp 7130 tractor from Case-IH 'Magnum' range, operating a Dowdeswell reversible plough typifies the trend to four-wheel-drive, assisted by many efficient modern control features.

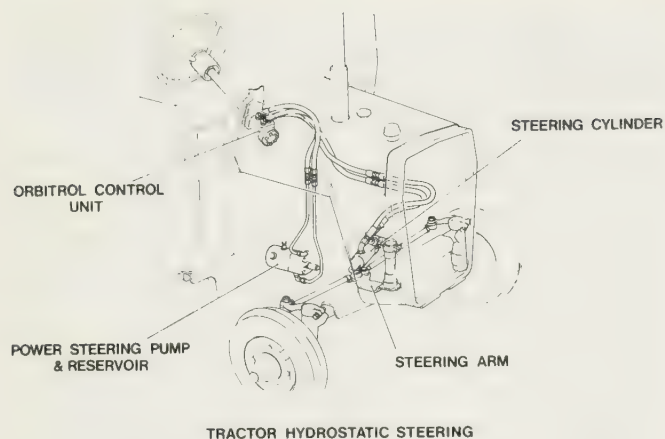


Fig. 2.3 Hydrostatic steering layout (*Massey-Ferguson 500 Series*). Circuit illustrated consists of hydraulic pump with integral reservoir, control unit beneath steering column, and double-acting ram. In normal conditions steering wheel operates spool, sleeve and metering valves which recirculate oil to reservoir or deliver it under pressure. If pressure from pump fails, non-return valve opens and enables a hand-pump element within the metering valve to be operated by the steering wheel to deliver oil from one side of the steering ram to the other, so maintaining steering, though with much increased effort.

type which necessitates re-arranging a dished wheel centre on an offset rim has, however, the merit of relative cheapness, and is rather more foolproof mechanically. Among aids to changing rear-wheel settings are (a) loosening wheel centre and driving complete wheel in or out by hand rotation of a pinion, attached to the wheel centre, which engages a rack cut along the axle shaft; and (b) power operation provided by temporarily disconnecting wheel centres from rims and driving the rims in or out by means of a scroll connecting the two parts. There is everything to be said for planning the row-widths of crops in such a way that the changing of tractor wheel widths is reduced to a minimum.

Transmission

Most four-wheeled tractors have the engine, clutch, gearbox, propeller shaft and drive axles all mounted in a rigid iron or steel frame. The two rear wheels are the sole or main traction members and the front wheels provide directional control. The rigid frame gives freedom from

misalignment of the transmission, and may at the same time provide a casing that is dustproof and waterproof. In well designed machines, the engine, clutch, etc., are all easily accessible. The power is usually transmitted through an easily adjustable plate clutch to a gearbox with at least ten forward speeds and two reverse. Many modern tractors have 10–20 forward gears, giving speeds of about 0.5–20 mph (0.8–32 km/h); but regulations in a few countries specify a maximum design speed of 25 km/h.

Gearboxes and transmissions are further considered in Appendix 2:

Designs of transmission systems vary considerably, but there is an increasing trend towards a fairly high-speed differential, wet disc-brakes and speed reduction by an epicyclic unit within the axle housings.

Braking systems

An early system of brake operation, illustrated in Fig. 2.4, provided the following facilities, using the same dry disc-brake operating elements for all methods of control:

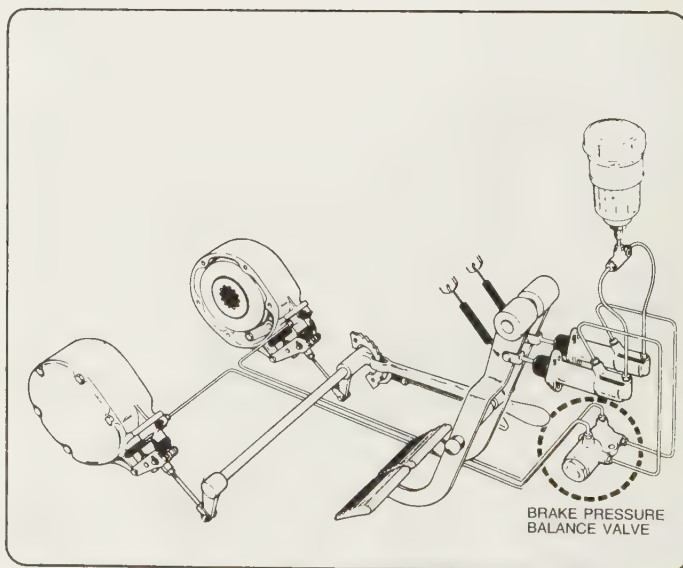


Fig. 2.4 Dry disc-brake control system for hydraulically operated independent or coupled service brakes, and mechanically operated hand (parking) brake. (*Girling*)

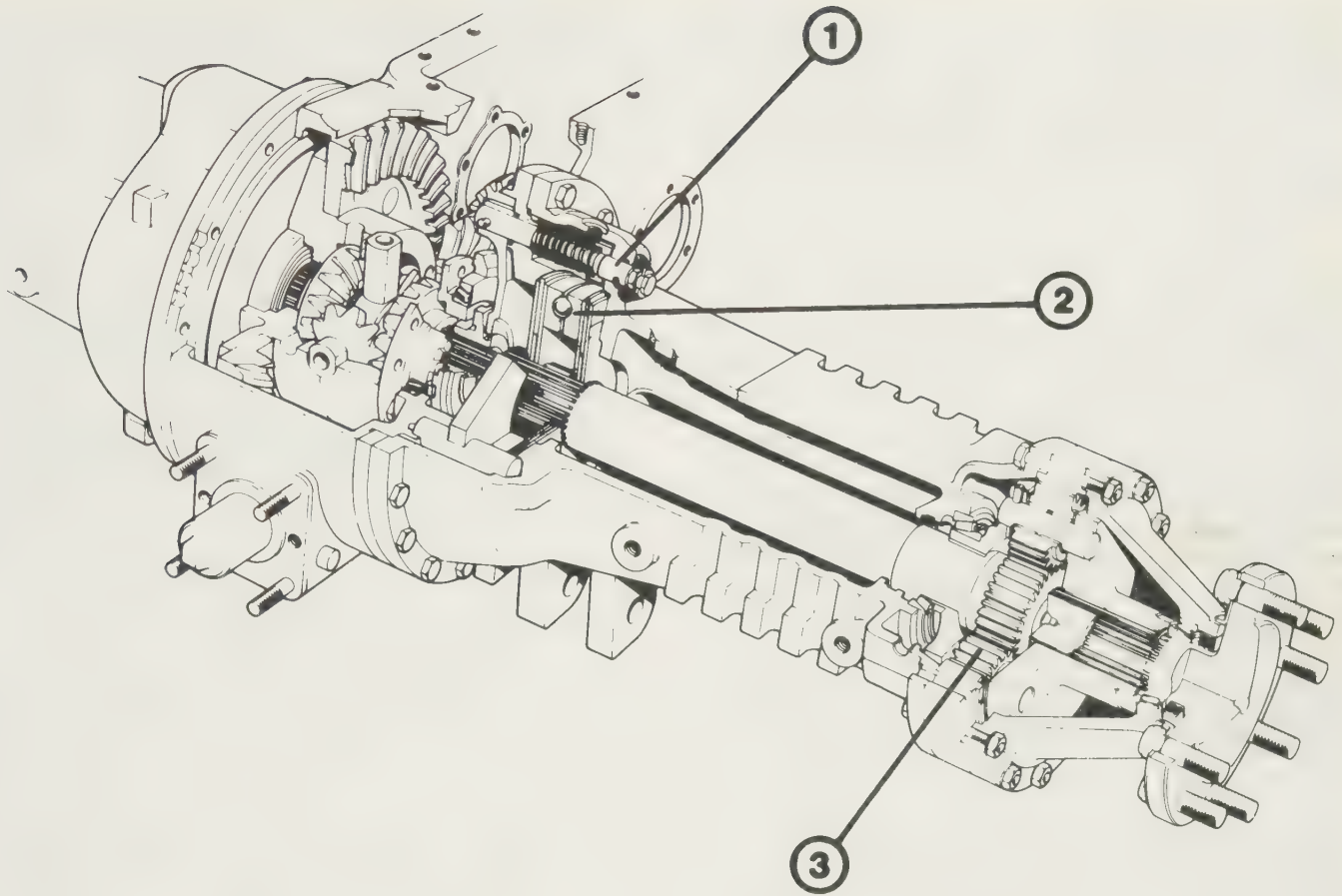


Fig. 2.5 Rear axle assembly (*Massey-Ferguson 300 Series*)
 1 Differential lock actuating assembly; 2 oil-cooled brake
 assembly; 3 final reduction gears (epicyclic).

The differential lock actuation is by hydraulic pressure, via a sliding clutch splined to the inner end of the right half-shaft, and carrying dog teeth which engage corresponding teeth on the differential carrier. Disengagement is by spring pressure.

- (1) Independent operation of right and left brakes by means of adjacent brake pedals, each working through a separate hydraulic system.
- (2) A brake pressure balance valve which ensures that when the two brake pedals are latched and used together, the pressures in the two sides of the hydraulic system are, within limits, equal.
- (3) A (parking) hand-brake which operates by a mechanical system on the same final brake components.

Disc brakes are further considered in Appendix 2, where Fig. A2.13 illustrates the dry type. Advantages of the oil-immersed type include effective cooling, with reduction of fade, and complete sealing against entry of water and dirt. In consequence, modern tractors almost invariably use the oil-immersed type, which may be a large diameter single disc or, more usually, a multi-plate type. (See Fig. 2.5.)

Where the tractor brakes are operated by a hydraulic

transmission system it is a simple matter to provide a suitable valve and hydraulic outlet at the rear for operation of trailer brakes. The control valve design should provide for the trailer brakes to be operated slightly ahead of the tractor brakes, and with a modulating action (see Fig. 21.6).

Differential lock

Whatever type of final drive is employed there is, of course, a differential gear (see Appendix 2) to facilitate turning without any skidding or undue strain. The differential is sometimes a nuisance in field work, because of the fact that the major portion of the tractor power may be delivered to the wheel meeting the least resistance. Thus, when one tractor wheel enters a greasy patch of land which gives poor adhesion it may skid and the tractor become bogged because most of the power is delivered to the skidding wheel. Use of a 'differential lock' can overcome this difficulty and it is a common feature on most wheeled tractors. A simple method of providing the differential lock is by means of manual engagement of jaw-type clutches. This mechanism, however, may preclude the engagement of the differential lock under conditions of high relative slip between the two rear wheels of the tractor, which is often the very condition under which the lock is most useful. On many tractors operation of the differential lock is provided by a hydraulically operated friction clutch which permits engagement or disengagement under any condition of relative slip. A sound four-wheel-drive transmission with a positive power-shift gearbox, easily engaged rear differential lock and automatic front axle differential lock, improves safety on slopes by providing assured 'engine-braking' assistance.

Gear-change on the move by 'Dual-power' systems

An adequate range of speeds and easy change-on-the-move are now essentials of good tractor design. There are many ways of achieving the objective. The widely-used 'Dual-power' system provides a single high/low change that is applicable to all of the normal working gears of a multi-speed box.

The high/low ('Dual-power') unit consists essentially of an epicyclic gear set (Fig. 2.6) giving an under-drive which reduces ground speed by 22% in any gear. Both direct drive and under-drive are engaged by separate

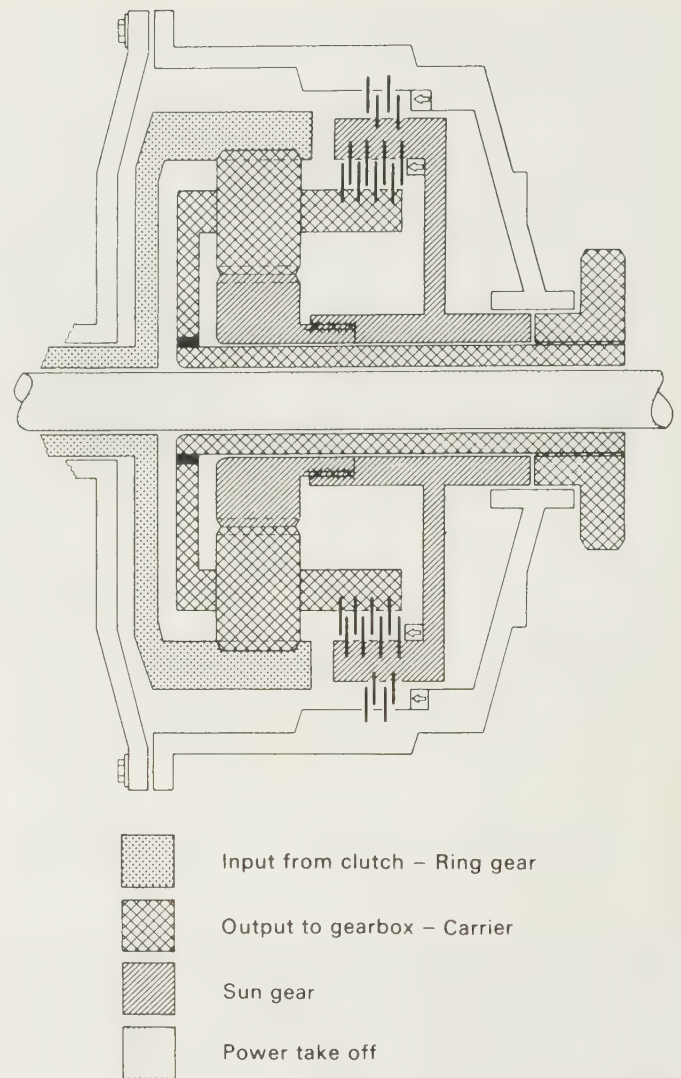


Fig. 2.6 Diagrammatic cross-section of hydraulically-operated epicyclic two-speed transmission unit for high/low change on the move. (Ford New Holland)

hydraulically actuated wet multi-disc clutch packs. The ring gear is directly connected to the input from the main clutch. For direct drive the sun gear is locked to the carrier by the inner clutch, and the whole unit turns as one. For under-drive the sun gear is locked by the outer clutch to the stationary housing, and this causes the planetary gears to 'walk round' the stationary sun gear, taking the carrier with them. The carrier turns in the same direction as the input ring gear at a lower speed.

Other economic uses that can be made of the basic Dual-power mechanism include a speed-shift that provides a higher road speed by reversing the compound planetary gears during assembly. This can provide a top gear of 40 km/h in a tractor built to a specification that requires it.

Transmission development trends

The David Brown 'Hydrashift' gave a valuable stimulus to development of advanced agricultural vehicle transmission systems specifically designed to meet the needs of tillage operations. It was years ahead of its time in many respects but did not achieve complete reliability, and was overtaken by other developments including a new type of synchromesh introduced by Leyland, and later the further advances made possible by computerised monitoring and automatic controls.

One of the remarkable aspects of the Massey-Ferguson developments already noted in Chapter 1 is the compre-

hensiveness of the microprocessor based packages, and the foresight with which the widely desired automatic 'Autotronic' transmission features were made standard on appropriate models, while the 'Datatronic' performance features were made available as an option which can easily be fitted when operators have accumulated some experience of handling microprocessor-produced data for management purposes.

Some leading manufacturers have opted for more restricted microprocessor packages for the present, but there can now be no doubt about the value of automatic transmission controls suitably related to four-wheel-drive engagement and disengagement, differential lock engagement and disengagement (related to headland turns), power take-off engagement, and blocking of gear changes likely to over-strain transmissions. These can reasonably be described as outstanding developments in both safety and efficiency: and progressive farmers will be well advised to put a fairly high value on such features.

Figure 2.7 illustrates the general arrangement of the

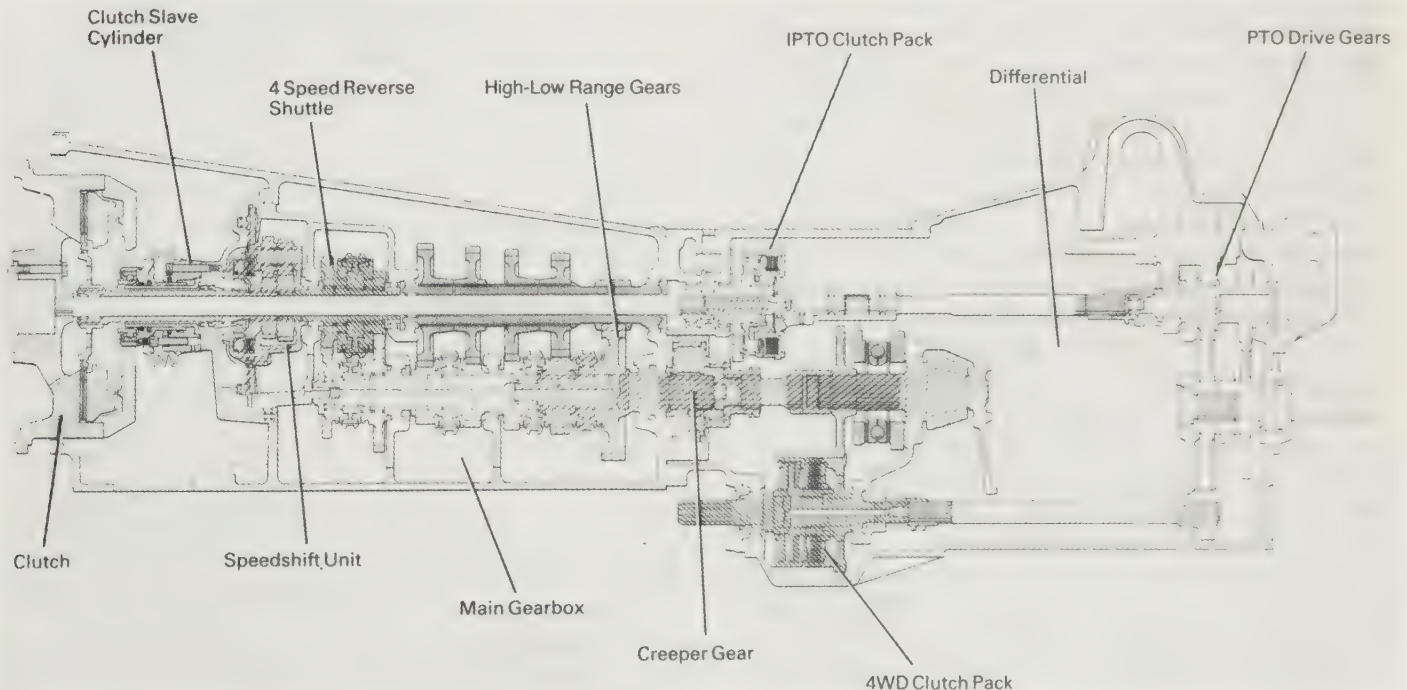


Fig. 2.7 General arrangement of 'Transaxial' transmission in the Massey-Ferguson 3000 Series, showing four-wheel-drive clutch pack and IPTO clutch pack.

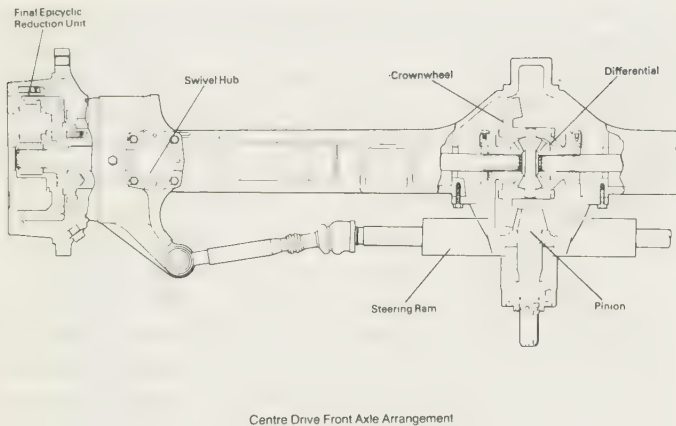


Fig. 2.8 Four-wheel-drive front axle arrangement on Massey-Ferguson 3000 Series. Four manufacturer's axle category ratings relate mainly to maximum axle loadings. Drive from the four-wheel-drive clutch pack (Fig. 2.7) is passed to a shaft with splined couplers at each end.

main transmission members in the Massey-Ferguson 3000 Series, where all components of the design named Trans-axle, which includes the rear axle, are common to the whole 3000 Series range. Five major castings include gearbox and clutch housing; centre housing; left- and right-trumpet housings; and lift cover. The clutch is a single-plate split torque type and has behind it a speed-shift unit and four-speed reverse shuttle, followed by the main gearbox and high-low range gears. The main gearbox has eight speeds provided by combination of the basic four-speed with the two-speed 'high-low'. All of these gears are in constant mesh, and all gear selections are made via synchromesh couplers.

The *reverse shuttle* arrangement is situated forward of, and drives, the main gearbox. It consists of four speeds; two forward and two reverse. When either of the two forward speeds is selected the transmission input shaft drives the mainshaft. The gear change is powered hydraulically as the lever passes across the neutral gate. When either of the two reverse speeds is selected the drive from the input shaft is transmitted to the mainshaft via a reverse idler gear cluster, thereby changing the direction of rotation of the gearbox output. (See isometric view in Fig. 2.9.) These gear arrangements provide 16 forward and 16 reverse speeds.

A *speedshift* system can be added to supplement this already comprehensive range of speeds. It is fitted forward

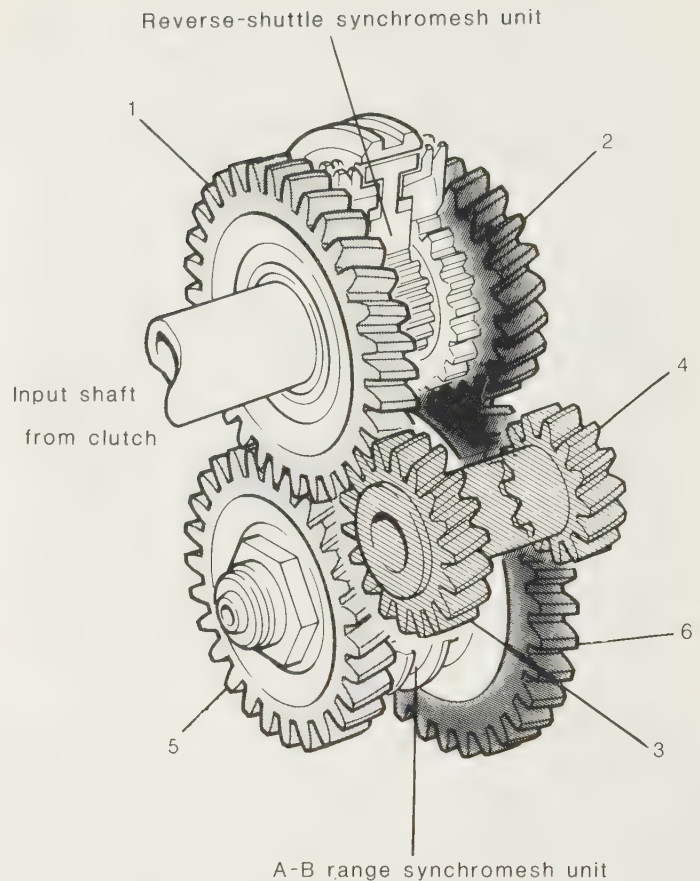


Fig. 2.9 Isometric view of four-speed reverse shuttle arrangement. It provides two ranges, A or B, via the A-B Synchromesh Unit. A forward and reverse speed is provided in each range by movement of the reverse shuttle synchromesh unit coupler. In the two reverse ratios, drive is passed via the reverse idler gears 3 and 4.

of, and drives, the reverse shuttle. It consists of a hydraulically operated epicyclic gearset, and provides the gearbox with an additional two input speeds, high and low, doubling the number of gearbox speeds to 32. Speedshift can be operated under load without interrupting drive to the tractor wheels.

An optional *creeper* gear arrangement can also be added to the output shaft to rear of the gearbox. It consists of another epicyclic reduction unit with a 4 : 1 ratio, which is usable only when the low range of the main gearbox is selected. Main use is for special purposes such as trench-digging.

The *differential* and rear axle components comprise crown wheel and pinion of spiral bevel type, supporting the differential on tapered roller bearings. From the differential the drive passes to final reduction epicyclic gearsets located at the inner ends of the trumpet housings.

The *differential lock* is situated within the differential housing and consists of a hydraulically operated dog-tooth coupler which is controlled by a push-button-operated electrohydraulic valve. The differential lock is also automatically controlled within the Autotronic control system.

The single-disc *oil immersed brakes* are hydraulically activated and are located between the differential assembly and the in-board final reduction gearsets. Each brake piston consists of a broad ring operating from a recess in the centre housing and acting directly on the disc. Both pistons are held in light contact with the discs at all times by the piston seals to give a self-adjusting action.

This brief outline gives only a glimpse of the engineering involved in the design and production of modern tractor transmissions.

Torque converter

For regular work with a front loader or fork-lift it is an advantage to have a transmission system that provides instantaneous shuttling from forward to reverse. Such facilities are among the advantages of the hydrokinetic torque-converter types of hydraulic transmission found in some industrial equipment. Many rough-terrain handling vehicles employ a combination of a fairly simple three forward, one reverse mechanical transmission in conjunction with an automatic power-shift torque converter which permits rapid clutchless changes on the move. With the direct shuttle from forward to reverse the engine can be run at high speed and power continuously.

Hydrostatic transmission

Hydrostatic transmissions used in farm tractors and power frames are of two main types. In one system there is one main hydraulic pump; hydraulic motors are mounted either in or adjacent to each drive wheel. In another system the hydrostatic transmission simply replaces the conventional mechanical gearbox. The pump and motor may then be built as a single unit, back to back, thus eliminating long oil pipes between pump and motor.

The distinction between 'hydrokinetic' and 'hydrostatic' transmissions is one of degree. In the former, typical of which is the torque converter found in automobile transmissions and many handling vehicles, energy is transmitted by the oil which is impelled at high speed so as to impinge on the blades of the turbine. Relatively little pressure is developed within the torque converter housing and it is the kinetic energy of the oil that transmits the torque. In a hydrostatic transmission the torque depends on the static pressure of the oil. Relatively small quantities of oil are pumped at high pressures to the hydraulic motor.

Transmission systems which depend solely on hydraulic pumps, motors and controls are rarely employed in multi-purpose agricultural tractors for economic reasons concerned primarily with the difficulty of securing a reasonably high power transmission efficiency across the wide range of necessary duties. On the other hand, use of hydraulics in control of tractor transmissions involving mechanical change-speed gears is widespread in new designs. Many new rough-terrain handling vehicles use torque converters. The use of hydrostatic transmissions can also be economically justified in specialised harvesters and in self-propelled sprayer/distributors, where the control advantages of an infinitely variable speed transmission can outweigh considerations of mechanical efficiency in power transmission.

Hydraulic pumps and motors

Increasing use is being made of hydraulic motors on various agricultural machines. These may be driven from the external hydraulic connections on the tractor or, in the case of the larger motors, as part of a separate hydraulic system driven by the tractor pto. Hydraulic motors have certain advantages over normal pto shaft or belt drives. The most obvious of these is the fact that the hydraulic hoses are flexible. Whenever a change in direction of the power transmission is required, this can be easily achieved with a hydraulic motor and its flexible coupling. Another important factor is the small size and weight of hydraulic pumps and motors in relation to their power output, e.g. a radial piston hydraulic motor with a maximum output of 9 hp (7 kW) weighs only 7 kg (16 lb), while a typical 7.5 hp (5.6 kW) three-phase electric motor weighs 90 kg (200 lb). Speed changes are obtained by changing the volume of oil flow or by altering the displacement of either the pump or the motor. There

is a wide variation in the oil flow rates from the hydraulic systems of different tractors. This ranges from as little as 11 l (2.5 gal) per min to over 90(20). In the case of fixed displacement motors especially, where the speed is directly proportional to the oil flow rate, this makes for difficulties in ensuring adequate speed control of the motor irrespective of the make of tractor with which it is used. The manufacturer has to match the motor to the lowest flow rate likely to be encountered. By means of a flow control valve, the excess oil can be made to bypass the motor but in so doing generates heat and results in loss of power. In some cases the heat may be such that an oil cooler has to be fitted in the system. Variable displacement motors overcome these difficulties to a large extent but are naturally more complex and expensive.

Power take-offs

A belt pulley was formerly widely used for driving stationary machines, but it has become an optional extra that is seldom called for. The normal method of drive is from the pto. The standard pulley is designed to take a 150 mm (6 in) belt, with the lower part of the belt in tension. Standard belt pulley speed is 950 m/min (3100 ft/min) with a tolerance of ± 30 m/min (100 ft/min), at the engine speed recommended for belt work.

The simplest type of pto in which the drive is automatically disconnected when the main clutch is disengaged, is unsuited to normal modern needs. Most manufacturers now offer a fully independent pto, engaged or disengaged by means of a separate pto friction clutch which bypasses the main transmission clutch.

In a favoured arrangement, engagement of the pto is effected by hydraulic pressure which forces the independent clutch discs and separator plates together to take up the drive. Return of the drive lever to the disengaged position may provide automatic braking of the pto as a safety measure.

Increasing complexity of distribution of engine power in high-powered tractors already outlined in Fig. 2.7 is further considered in relation to main tractor clutches in Appendix 2, Figs A2.7 and A2.8 and A2.9. Clutches of varied types including one called 'Split Torque' have quickly become an important element in high-powered tractor designs. The design called 'Dual Clutch' (Fig. A2.8) remains widely used and considered suitable for light tractors of medium power.

Pto speeds and shaft details are standardised on an international basis, the current ISO types, which are also British Standards, being as shown below.

Type	Diameter		Rev/min	Suitable for pto power at rated speed up to	
	mm	in		kW	hp
6 straight splines	35	1 $\frac{3}{8}$	540	48	64
21 involute splines	35	1 $\frac{3}{8}$	1000	92	123
20 involute splines	45	1 $\frac{3}{4}$	1000	132	176

$$\text{hp (Imperial)} = \frac{\text{torque (lbf)} \times \text{rpm}}{5250}$$

Front pto systems

Front ptos have been developed mainly to meet a need to drive front-mounted and rear-mounted or trailed machines simultaneously. Combined operations include rotary mowing at both front and rear; mowing at front and loading at rear; windrowing and baling; power harrowing and drilling; drilling and spraying, etc. Many tractors are now designed from the start with quick

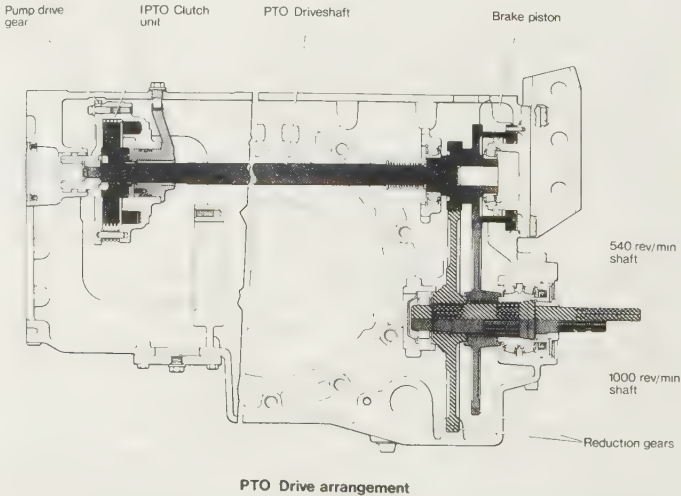


Fig. 2.10 Independent pto hydraulic clutch unit drive. Change of pto speed requires stub shaft change. For operation with Series 3000 four-wheel-drive see transaxial general arrangement in Fig. 2.7. (Massey-Ferguson)

hitch and pto at both front and rear, usually with a choice of 540 and 1000 rpm. Where high-powered tractors are to be used in this way, four-wheel-drive is essential; it seems certain that such tractors will increasingly be designed from the beginning for combined front and rear linkage use.

The existing front-mounted linkage and power take-off standards are basic in content, and do not attempt to provide answers to all of the difficult front linkage application problems. The British Standard 6818 (1987) is identical with ISO Standard 8759 (1985) apart from minor terminological differences which are noted in the British version. Both comprise Part 1, Specification for Power Take-off, and Part 2, Specification for Front Linkage. The standards go as far as is practicable at present, but complete success with equipment such as a mower-conditioner or deep-working tillage equipment requires some ingenuity on the part of the implement or machine manufacturer to ensure a level of performance that is the norm for rear-mounted or trailed equipment.

Figures 2.31(a) and (b) give some idea of the aims and the mechanical engineering involved in front mounting the Krone 2.8 m cut mower-conditioner intended for use with a rear-mounted similar machine to secure high-speed work in preparation for making wilted silage. The aim is to take forward from the front-linkage lift triangle a light but rigid frame which will support a front bar on which hinge-mounted mower units are able to float in a vertical plane with the aid of adjustable spring support. Similar designs may be seen also in Chapter 12.

Drawbar

For many purposes, a tractor delivers the power of its motor through a drawbar. A common type consists of a quadrant that is rigidly attached to the transmission housing, and a swinging member which is easily detachable and can be adjusted in height, often by bolting an extra short member to the rear end to form a clevis. BS 1495: 1970 gives details of drawbar heights and dimensions designed to secure ease of attachment of implements and trailers. One of the important dimensions incorporated in the standard is the vertical distance between the ground line and the top of the drawbar, and this should lie between, or be adjustable to, 12 to 18 in (300–450 mm). Most manufacturers provide a range of both vertical and horizontal adjustments to facilitate hitching to all kinds

of implements. When the engine is exerting its power in driving the rear wheels, the front of the tractor tends to rise owing to the 'torque reaction', i.e. the tendency of the drive wheels to remain stationary while the engine winds the tractor round the back axle. This transfers weight to the rear wheels, the front tending to rear off the ground. Distribution of tractor weight and location of the drawbar must be such that there is always sufficient weight on the front wheels to make steering possible.

Wheels

Four-wheeled tractors normally have three-point suspension, the front of the frame being centrally attached to the axle by means of a horizontal trunnion. This allows the wheels to follow the contours of the ground quite freely. The design of the traction wheels should aim at securing the best possible adhesion with a minimum absorption of power. The tractor often works on loose surfaces, and the power expended by it in propelling itself over the land is considerable. In general, the less the disturbance of the soil, the lower is the rolling resistance. Other things being equal, the greater the diameter of the traction wheels the less the wheels sink into the soil and the better the grip.

Adhesion is increased by increasing the weight, but Table 2.1 (column 3) shows how the weight per horsepower has been reduced since 1920 while, as column 4 shows, the ratio of maximum pull to test weight steadily increased until the influence of fitting pneumatic tyres caused a check in the general trend. Current tests are

Table 2.1 Progress in the reduction of tractor weight and fuel consumption

Period in which tested*	Fuel consumption on drawbar rated load (lb per hp hour)	Test weight per maximum drawbar horse-power (lb)	Ratio of maximum pull to test weight
1920	1.63	349	0.44
1923–6	1.15	275	0.62
1927–30	1.01	213	0.69
1935	1.05	215	0.70
1946	0.73	213	0.66
1955	0.59	202	0.65
1961	0.61 [†]	191	0.73
1966	0.58 [‡]	178	0.78

* Figures based on all wheeled tractors tested at Nebraska in the periods stated.

[†] Average of 11 diesel, 5 petrol and 3 propane.

[‡] Average of 13 diesel, 9 petrol and 4 propane.

carried out with varying but usually large amounts of ballast weight added to the tractor.

Table 2.2 gives some average figures, calculated from OECD test reports, for fuel, power and unballasted weight relationships for small and medium-powered tractors in the 1980s. The figures are not directly comparable with the earlier Nebraska test results but generally show a continuation of the trend towards improved power: weight ratios as improvements in engine designs are utilised.

The tyres used for normal drive wheels are low-pressure types, with pressures of 12–20 lbf/in² (0.8–1.4 bar). Lower pressures are used in special-purpose low-ground-pressure vehicles (page 48). The tread used for field work is usually of the open centre pattern, i.e. with no rib down the centre as commonly used on dual-purpose vehicles such as a Land-Rover. This is because the traction efficiency of a tractor tyre is dependent upon the tread bar being able to penetrate the soil when conditions are sticky. The flexing of the tread bars which occurs when the tractor is at work assists in freeing soil from the spaces between the bars, and so produces a self-cleaning effect. To help achieve this, the tread bars should be separated and widely spaced.

For travel on tarmac roads and on hard dry soil the tread requirements are quite different. Here the problem is wear of the tread, and there is no difficulty over traction. The rate at which a tyre wears is related to the quantity of rubber in contact with the surface. The closer

the tread bars, the longer will the tyre last. The modern tractor tyre is therefore a compromise between these two opposing characteristics. The walls are made fairly light, and as the load increases the tyres flatten and cover more ground. Four- or six-ply ratings are used on the small to medium tractors but larger machines frequently use eight- or ten-ply tyres to cope with the extra weight. The trend is towards wider-based tyres, with walls rather short in proportion to the width. British Standard recommendations for agricultural tyre sizes (BS AU 50: Section 4a: 1972) use the dual standard method for giving tyre dimensions, since modern tractor tyres are designed to be used on a variety of rim sizes. Tyre dimensions show first the maximum section diameter followed by the normal section diameter and then the wheel centre diameter, e.g. 13.6/12–38 for what is commonly called a 12 by 38 tyre.

A tyre supports its load by deforming until the ground contact area multiplied by the inflation pressure equals the load applied. To avoid damage to side-walls, deflection must be limited, usually to about 20% of tyre section height. Radial tyres compared with crossply have an increased area of footprint which results in improved flotation, lower rolling resistance and an increased pull capability, typically about 8% better than crossply at moderate levels of slip. Radial tyres have a much longer life – typically estimated by users at 50 to 150%.

For work in row crops where heavy loads have to be supported, dual narrow wheels may provide the best solution (e.g. in sugar beet harvesting). Pairs of tyres about 240 mm wide are connected together by strong spacers at about 480 mm centres, so that each tyre can run down the centre of the inter-row space.

Studies of draught tillage by Silsoe Research Institute show that optimum forward speeds for conventional implements are approximately:

Table 2.2 Average specific consumption, power and unballasted weight relationships for OECD tractor tests dated 1982* and 1986/7**

<i>Power group (kW)</i>	<i>Number in group</i>	<i>Specific fuel consumption at maximum power (g/kWh)</i>	<i>(lb/hp/h)</i>	<i>Unballasted weight per maximum drawbar power (kg/kW)</i>
(Dated 1982)				
B (40–49)	12	258	0.42	78
C (50–59)	14	264	0.43	75
D (60–69)	20	261	0.43	70
Dated 1986 or 1987**				
B (40–49)	9	258	0.42	81
C (50–59)	17	258	0.42	77
D (60–79)	11	254	0.41	77

* Tractor Test Results, 1982. A summary of OECD and Nebraska Test Reports. Royal Agricultural Society of England in conjunction with NIAE.

** Based on test report figures from *Agricultural Tractors 1989* published by AFRC Engineering, Wrest Park, Silsoe, Bedford.

Implement	Speed	
	(km/h)	(mph)
mouldboard ploughs	6	3.7
medium depth tined implements	8	5
shallow cultivation and grain drilling	10	6

Tractors of 60 kW or above pto power, fitted with standard tyres, can often only carry enough ballast weight for

optimum efficiency at the lower speeds if equipped for four-wheel-drive or fitted with much larger tyres than standard. Figure 2.11 shows typical relationships between speed and weight needed on drive wheels. When calculating weight, the weight transfer from implements such as ploughs can be taken as approximately equal to the static weight of the mounted implement.

An empirical formula for total load required is:

$$\text{load required, lb} = \frac{600 \times \text{tractor power (hp)}}{\text{forward speed (mph)}}$$

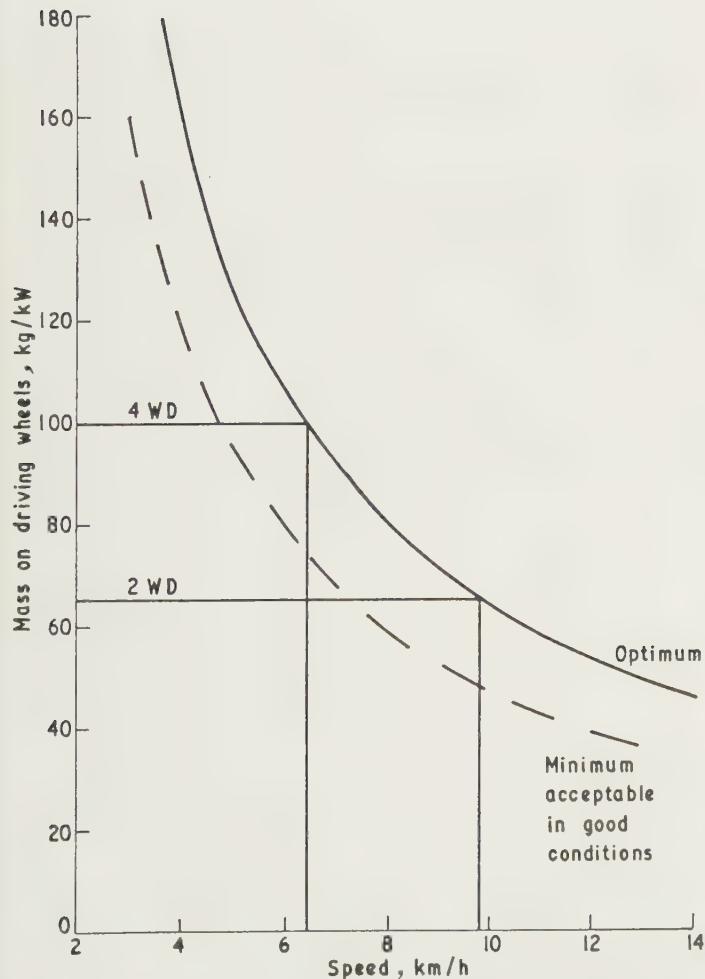


Fig. 2.11 Weight on tractor drive wheels needed for optimum traction efficiency at different speeds. Lines for two-wheel-drive and four-wheel-drive examples for a particular tractor range fitted with standard tyres. (Silsoe Research Institute graph)

One of the potential advantages of well-designed combinations of front and rear mounted equipment is that necessary strengthening of front frames and axles for four-wheel drive, and the weight of the mounted equipment itself, often eliminate any need for front ballast weights on the tractor.

Traction aids

There are several methods of improving the traction of tractor driving wheels. There is unfortunately no hard and fast rule to guide the farmer, but generally adding weight or ballast is best for the lighter soils. For the heavier more cohesive (clay) soils, wheel strakes, etc., will probably give better results than merely adding weight. At the same time as giving increased traction, however, strakes, cleats and other devices which bite into the soil also increase the rolling resistance.

As tractor engine powers increased, wheel slip of pneumatic tyres became an increasing problem, and water ballasting was tried as a cheap method of reducing slip. Disadvantages included inefficiency of the extra weight where it resulted in very hard tyres of almost cylindrical cross section. It was not long before radial tyres were developed, and their soft walls provided foot-prints of



Fig. 2.12 Twin heavy-duty dual wheels for high-powered tractors are fastened together by adjustable-length hooks and eyes, using over-centre levers. Spacer steel bands secure best performance in difficult conditions. (OPICO)

considerably greater area, leading to improved drawbar efficiency without excessive weight.

Modern tractors can be supplied with a weight frame at the front for carrying an easily varied number of wafer-shaped cast-iron weights. Individual weights are usually about 27–41 kg (60–90 lb). A complete set may add up to about 360 kg (800 lb) to the front weight. Adjustable strakes which retract when not required are not so commonly used as they once were.

Other wheel attachments commonly used are cage wheels. These may be fitted in addition to or instead of pneumatic tyres to avoid excessive compaction and leave the land level. This is particularly important for spring work on seedbeds and for drilling sugar beet and other crops with similar requirements.

Tractor-engines

Appendix 1 contains a brief account of the principles of operation of the common types of diesel tractor engine. Many types of engine are employed in tractors, the vertical multi-cylinder four-stroke type being most common. Diesel engines have become standard equipment for both medium-powered and large tractors. Owing to its high cost, petrol is normally used only for very small engines

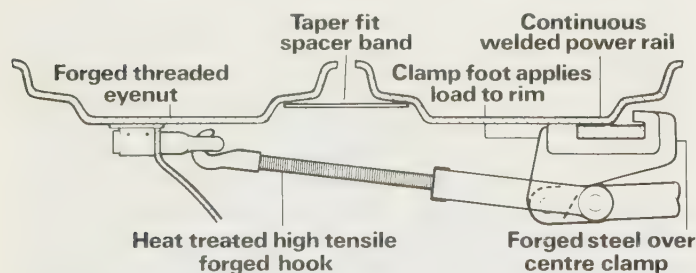


Fig. 2.13 Construction and fitting for Stocks heavy-duty dual wheels. The taper fit spacer band fits precisely into the tapered bead section of the tractor rim, evenly distributing the load. The power rail is continuously welded into the rim, thereby strengthening it. A welding process using tubular welding wire and Argon/CO₂ gives maximum strength and no distortion. The clamps are drop forged from high quality steel for trouble-free operation. Fitting: rim disc nuts are replaced at the recommended intervals by eyes supplied: the dual wheel is placed in position and one of the snap-on over-centre clamps is attached to the power rail opposite each threaded eyenut. Each is then tightened using the lever supplied. (Richard Stocks)

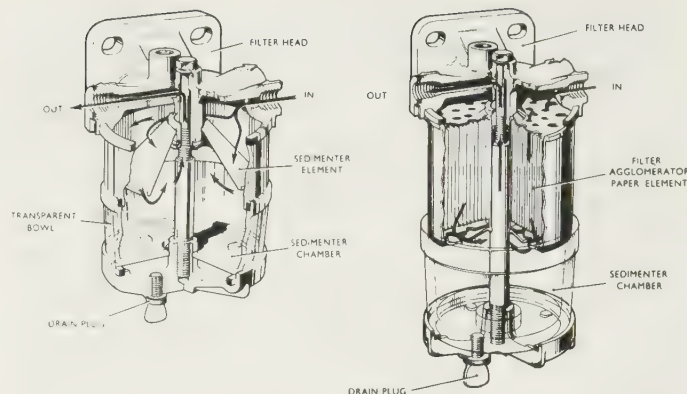


Fig. 2.14 (left) Primary fuel sedimenter for removal of water and relatively large particles of rust, metal or grit. Draining interval can be adjusted to suit individual needs. (CAV Type SS)

Fig. 2.15 (right) Second fuel filter consisting of a combined filter and an agglomerator-sedimenter. Fine water droplets forced through the pores of the paper filter element coalesce into larger droplets which are deposited by sedimentation. (CAV Type FAS)

such as are found in the smallest garden tractors. Engine speeds are usually lower than in cars and trucks.

British diesel tractor engines are usually of the full-diesel four-stroke multi-cylinder water-cooled type, and run at about 2000 rpm rated speed, with maximum torque at about 1200–1400 rpm. Similar engines are used in many countries but in some, engines of quite different types are found. For example, air-cooled diesels are popular in Germany.

Whatever the type of diesel engine employed, it is essential that the fuel be free from all contaminants, solid or liquid, when it reaches the injectors. Tractor manufacturers take elaborate precautions to ensure absolute cleanliness of the diesel fuel by providing several filters in the line from the tank to the fuel injection pump. Typically the fuel passes through a sediment bowl which allows water and heavier solid particles to settle out; then to at least two paper element filters in series. The first one of these may be an agglomerator type in which there is further provision for the collection of water in an enlarged transparent bowl below the element. The filter elements normally used are made of impregnated paper and are replaced by new ones at servicing periods. They should not be cleaned.

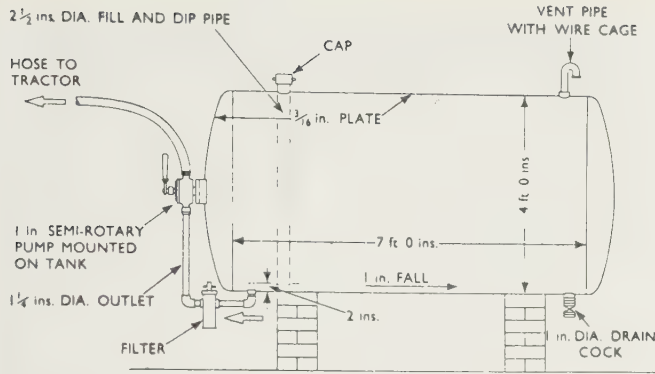


Fig. 2.16 Diesel fuel tank, capacity 600 gal (2730 l).

Most sedimenters, once full of water, provide no further protection. Automatic types provide either an electrical warning signal or automatic fuel cut-off if the water in the bowl reaches a critical level. Sensing is usually by a float with specific gravity less than that of water but greater than that of diesel fuel. For farm storage a welded steel cylindrical tank mounted on brick piers is often suitable (Fig. 2.16). In some situations, filling tractors by gravity may be practicable.

It is important to arrange for a slight fall to a drain-cock to facilitate the removal of sludge, and it is always advisable to fill tractors just before the storage tank is filled, so that any sediment has a chance to settle before the new batch of fuel is used.

A main source of contamination by water is condensation on the inside surface of the tank. This is reduced by locating the tank beneath a roof and by keeping it as full as practicable.

Air cleaner

An efficient air cleaner is a necessity for any type of tractor engine. Engines consume vast quantities of air and it is essential for the air to be completely free from abrasive particles. Engines can be ruined in a matter of minutes when the air is contaminated by abrasive dusts. The air intake is usually positioned at a high point so that it has the best chance of drawing in clean air. The air first passes through a pre-cleaner so constructed that the induced air is given a swirl, thus flinging the heavier particles of grit through louvres around the edges, or into a glass collector which may be regularly emptied. The air then

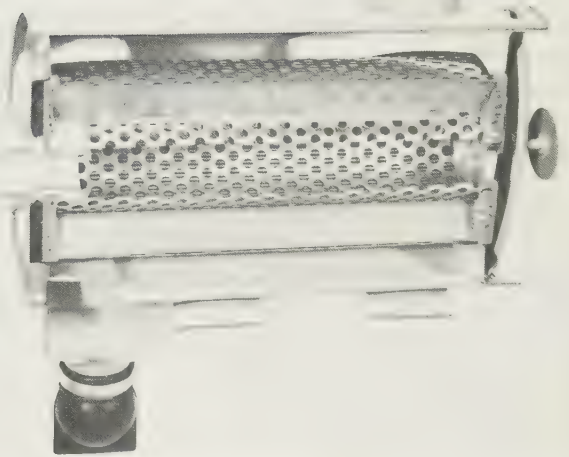


Fig. 2.17 Air cleaner (AC-Delco)

Section of heavy-duty dry type comprising a centrifugal pre-cleaner with automatic dust unloader, and a long-life high efficiency impregnated paper filtering element which can be washed 10–12 times before requiring renewal. Dust enters bowl at bottom via slot in baffle plates.

passes to the main air cleaner which may be either an oil bath or a dry element type.

In the oil bath air cleaner, the air is cleaned when it impinges on the surface of the oil and the particles are entrapped while the air is deflected up through the filtering element. In the process, a little oil is also carried up into the filtering element, so adding to its effectiveness.

The dry element air cleaner has a replaceable impregnated paper element, and is at least as effective as the oil bath pattern. These elements can be cleaned by tapping gently against the palm of the hand or by blowing against the normal direction of air flow with compressed air. There may be an additional element in case the main filter gets damaged. On some tractors these air cleaners are fitted with a restriction indicator which, when the flow of air to the engine decreases due to increasing restriction of the filter element, raises a red warning signal for the driver.

Reference is made in Appendix 1 to the now normal practice with turbo-charged engines of using a modern automatic disposal centrifugal cleaner which has the dust continuously removed and discharged to atmosphere by the exhaust gases.

Oil filter

Grit and other foreign materials should be removed from the lubricating oil by means of an efficient oil filter. Filters are of two main types, 'full-flow' and 'by-pass'. In the more commonly used full-flow type, the oil pump situated in the crankcase forces all the oil through the filter before it is delivered to the main bearings, while in the by-pass type only a proportion of the oil pumped, usually 5–10%, passes through the filter on any one circuit. The full-flow filter may have a rather coarse element such as fine brass wire or felt, and some such filters are designed so that they can be easily cleaned. More usually, however, the filtering element consists of material such as fine felt or impregnated paper, and cannot be cleaned by the operator. These finer types of element must be replaced at regular intervals, since any attempt to wash them in petrol is likely to result in inefficient filtration. The manufacturer's instructions should be followed in all cases, for efficient oil filtering is an important factor in securing a long engine life. With full-flow filters, pressure-regulating and safety devices must be included in order that lubrication may not fail if the filtering element becomes clogged. A simple safety device consists of a ball valve which is normally held on to its seating by the force of a light spring, but rises from its seating and allows the oil to be short-circuited direct from the inlet to the outlet pipe when the pressure in the inlet pipe becomes much greater than that in the delivery pipe. With the full-flow type the filtering element itself is often spring-mounted, and is automatically by-passed if excessive pressure develops.

Hydraulic lifts

A tractor hydraulic lift comprises a pump to provide oil under pressure; a control mechanism which regulates delivery, and a ram on which the oil pressure acts to lift or lower mounted equipment. The ram is usually built in at the rear of the tractor and operates a horizontal cross shaft to which are attached the lift arms. Alternatively or additionally oil may be fed to a built-in front linkage or by flexible tube to external lifting cylinders on either the tractor or driven machines.

Main types of pump include multi-cylinder reciprocating with plungers driven by cams or eccentrics; a gear type

similar to that used for engine lubrication but more accurately constructed; and various special types of high-efficiency rotary pump. The pump must be capable of operating at a fairly high pressure, and must deliver a sufficient volume of oil to complete the lift in not more than two seconds.

The method of control naturally depends on the application required. If the only operation to be reckoned with is the raising and lowering of lift arms by means of a built-in ram, a fairly simple form of control will suffice. This consists of a valve which in one position allows the oil to pass from the pump to the ram cylinder, and in the other position releases the oil from the cylinder and allows that coming from the pump to pass straight back to the reservoir.

In the 'open-centre' system a constant displacement pump supplies oil to a three-position valve. In the neutral position the oil flow is returned directly to the sump. Lifting or lowering is achieved by displacing the valve towards either the 'raise' or 'lower' position. Because there is no reserve of oil under pressure when the valve is in neutral, this simple 'open-centre' system is not suited to operation of servo mechanisms including 'draught control' systems referred to later. All tractors with 'draught control' need a more complex hydraulic system. If a constant-displacement pump is used, it is possible to provide a supply of oil under pressure without excessive overheating by the use of such devices as variable orifice and unloading valves. The higher the pressure used, the greater the power absorbed and the greater the likelihood of overheating. Variable-displacement pumps provide means of adjusting the supply of oil to the needs of the system while still maintaining the required pressure within the system. (This is called a 'closed-centre' system.)

The pump in a closed-centre system is usually simply self-regulated by the oil pressure. In a radial-piston type (e.g. John Deere), as pressure builds up to the level required, oil pressure on the pump pistons moves the pistons away from the cam drive. Conversely, as pressure falls, springs force the pistons down on to the cam drive until full hydraulic pressure is restored.

Basic implement control systems

More complex systems of implement control began with the Ferguson system, embodying automatic 'draught control', now widely adopted. 'Response control' is a refine-

ment of draught control which permits adjustment of the sensitivity to suit working conditions. Most manufacturers also provide 'position control', which allows the implement to be precisely located in relation to the tractor.

Most modern implement control systems are applied through a three-point linkage, consisting of one upper link which is usually in compression, and two lower links which are in tension. The sensing for draught control systems was first applied through the upper link, but many designs have sensing through the lower links, and some sensing of torque in the tractor transmission system.

Automatic draught control: The principle of automatic draught control is illustrated in Fig. 2.18. Variations in the pull exerted by the tractor on the implement deflect the load spring, and result in a corresponding movement of the hydraulic control valve. The position of the control lever determines the spring load required to return the valve to neutral, and so controls the draught. Some of the basic elements of widely used Massey-Ferguson automatic draught control systems applicable to light three-point linkage tractors are illustrated in Fig. 2.19.

Forward movement of the tractor causes the implement top link to compress the draught-control spring (6). This causes the plunger (7) to contact the draught control rod (8) and move the whole linkage forward (to right). This allows the cam (2) and levers 4 and 5 to move in directions opposite to those shown by the arrows, so shifting the control valve from discharge to neutral. The implement depth is now stabilised, and corresponds to the position of the control valve lever (5). Moving the control lever farther forward puts the valve in discharge, and the implement depth increases until sufficient extra force has built up to compress the control spring and return the valve to neutral. Moving the lever rearward has the opposite effect.

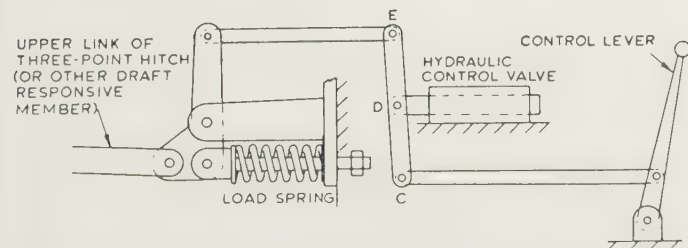


Fig. 2.18 Basic principle of draught control.

Provided draught forces against the control spring remain relatively constant, the system automatically maintains the implement at the depth selected by the control lever irrespective of ground undulations. Changes in soil texture and resulting changes in draught loads against the control spring sufficient to alter the desired depth of work are compensated by moving the control lever to a new position.

Response sensitivity control: Sensitivity of response adjustment is provided to ensure that reaction to draught control signals is neither too fast and violent nor too slow. A too-rapid automatic lowering of the implement

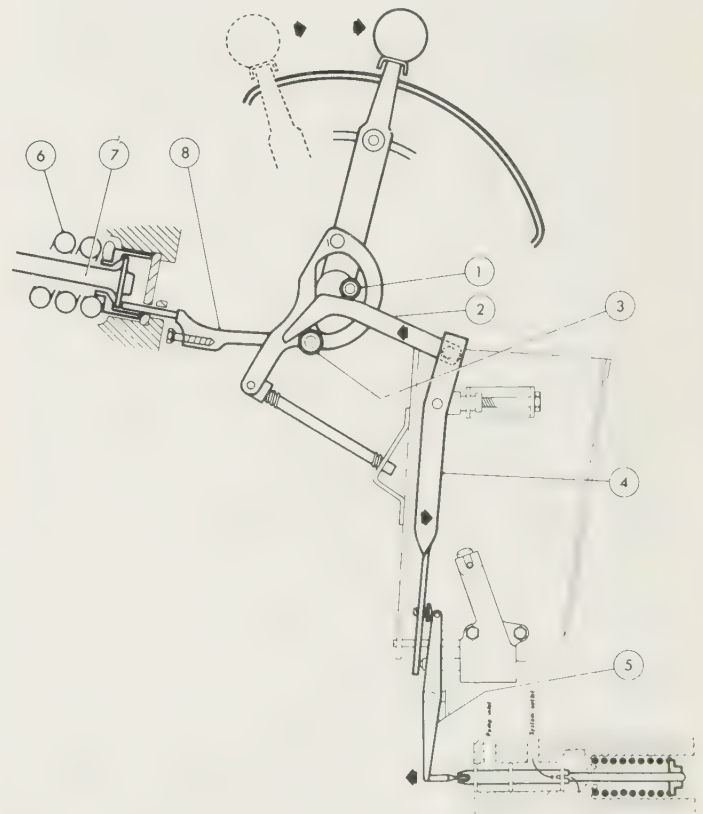


Fig. 2.19 Draught control—implement lowering (Massey-Ferguson)

1 Eccentric roller, 2 Draught control cam, 3 Roller on draught control linkage, 4 Vertical lever, 5 Control valve lever, 6 Draught control spring, 7 Draught control plunger, 8 Draught control rod.

removes transferred weight from the tractor and results in loss of traction. With a good design an automatic drop control feature limits oil flow during operator-initiated implement lowering, even if the main control lever is thoughtlessly pushed to the full lowering position; conversely, a rapid lift out of work is provided even on the low-sensitivity setting. With Load Monitor control (page 35) usual sensitivity needs are maximum for trailed, medium for semi-mounted and minimum for mounted implements.

Position control: With automatic position control, any given position of the control lever represents a corresponding position of the implement relative to the tractor. The principle is illustrated by the linkage outlined in Fig. 2.20. The solid outline shows the stabilised condition, with the control valve in neutral position. Movement of the control lever to the dotted position moves the control valve to a position in which the hydraulic cylinder is actuated. The implement is thereby raised, and this returns the control valve to the neutral position. Position control is employed for hoes, buckrakes, mowers, sprayers, etc., where the aim is a constant working position, uninfluenced by draught.

Pressure control: This is an extension of the normal tractor hydraulic lift system which enables the driver to control the pressure within the lift cylinder (or in an external ram) to give a controlled lifting force. A valve, variably spring-loaded from the control lever, acts on the main hydraulic control valve through a servo mechanism to limit the supply of oil to the pump to maintain the selected

pressure. The method of controlling the pressure by means of restricting the flow to the pump avoids unnecessary pumping and consequent rise in temperature of the transmission oil.

The main function of the pressure control system is to provide a controlled degree of weight transfer on to the tractor rear wheels when towing trailed implements. A special coupler fits on to the lower links of the tractor and applies a lifting force through the chain to the implement drawbar. Since the front of the implement drawbar is secured firmly to the normal tractor drawbar, the reaction to the lifting force is transferred downwards through the lower links and on to the rear wheels of the tractor. By maintaining the desired oil pressure in the lift cylinder, the amount of weight transfer remains constant over undulating ground, irrespective of relative movement between the tractor and the trailed equipment.

Safety devices are incorporated to prevent the tractor rearing over backwards when going up steep inclines, or if the connection to the implement should fail. The length of the chain is adjusted so that the limit of upward travel of the lower links is reached before the tractor front wheels rise too high. In the event of the drawbar becoming disconnected, the spring-loaded socket which attaches the chain to the coupler disengages when subjected to a near horizontal pull and forms a safeguard against the tractor rearing.

Lower-link sensing: When a 'closed-centre' hydraulic system is employed it is practicable to employ lower-link sensing for load control, and this has advantages in the case of long semi-mounted equipment. When upper-link sensing is employed for long semi-mounted ploughs it is necessary to provide an additional pivot in the hitch to ensure that there is always a compression force in the top link. No such problems arise with lower-link sensing.

Figure 2.21 and 2.22 illustrate two distinct methods of operation of lower-link sensing involving transmission of automatic draught control signals primarily by hydrostatic pressure. Both are designed for use with the ASAE pick-up hitch.

In Fig. 2.21 (Type A) the lower link forces act first on a bending bar, and a servo valve is used to amplify signals to the rock shaft. In Type B (All-hydraulic) the load on the lower links is directly monitored by hydraulic check valve, and hydrostatic load signals are transmitted to the rockshaft.

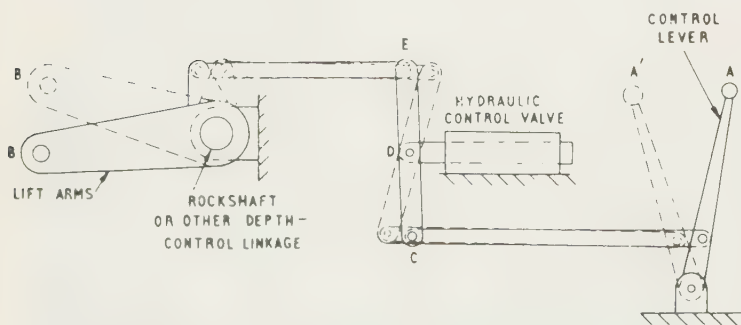


Fig. 2.20 Basic principle of position control.

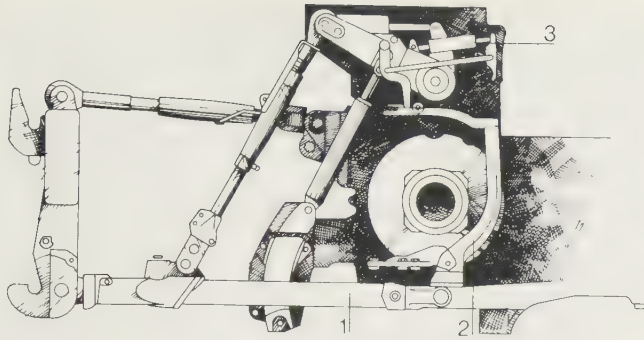


Fig. 2.21 Lower-link automatic draught control system using ASAE pick-up hitch. (John Deere)
Type A Hydraulically assisted. Lower link 1 actuates a bending bar 2; a servo valve 3 detects the changes and amplifies signals to the rock shaft.

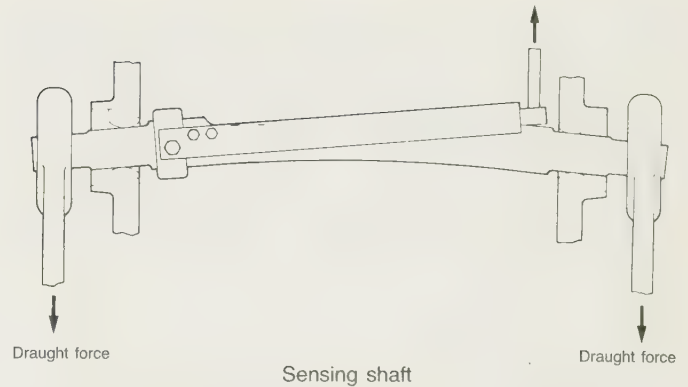


Fig. 2.23 Automatic draught control-lower-link sensing. (Early Massey-Ferguson 2000 Series)

A draught-sensing shaft connects the lower links: it bends forward in the centre when implement forces act on the overhung ends. The movement is transmitted via a sensing arm, rollers, cam and sensing rod to the hydraulic control system which incorporates sophisticated adjustments.

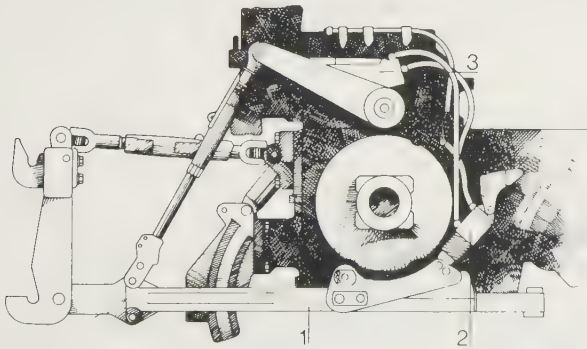


Fig. 2.22 All-hydraulic (Type B) lower link automatic draught control system. (John Deere)
Load on the lower links 1 is directly monitored by hydraulic check valve 2; hydrostatic load signals are transmitted to the rockshaft 3.

Automatic draft control lower link sensing in the Massey-Ferguson 2000 Series employs a sensing shaft as illustrated in Fig. 2.23. The sensing shaft bends forward in the centre when implement forces act on the overhung ends. A relatively simple method of lower link sensing introduced by Bosch has become widely used in conjunction with computerised tractor controls (see Fig. 2.27). The load-sensing elements are neatly incorporated in the lower-link hitch pins.

Transmission torque sensing (Load Monitor): Load Monitor (Ford) is a hydraulic control system designed to operate in addition to draught control and position control. It can be used instead of draught control with long fully mounted implements, and is particularly applicable to long semi-mounted equipment or to trailed equipment controlled by an external hydraulic cylinder.

The sensing unit is a mechanical coupling incorporated in the main drive just ahead of the differential. It senses torque by means of a 'Belleville' spring unit, consisting of balls which are held in ramps by spring pressure. The whole unit rotates with the shaft, and increase of torque causes the outer part to move endways as the balls climb the ramps. The movement is mechanically connected to the main hydraulic control valve.

For semi-mounted equipment a remote depth-regulating hydraulic cylinder at the rear end of the implement works in unison with the main tractor lift cylinder. The remote cylinder is connected in series with the main ram. As oil enters the external cylinder from the pump, an equal amount of oil is displaced from behind the external ram piston and is forced into the main ram cylinder. The external ram has slightly less displacement than the main ram, and reaches the end of its stroke slightly before the

main ram. When this happens, a check-valve at the end of the remote cylinder is automatically opened, and oil flows through it into the main ram to complete the lift.

When load-monitor control is selected, draught signals sensed through the top-link draught control spring have no effect on the internal control linkage.

Load monitor can be used to regulate depth of work on hydraulically lifted trailed equipment such as disc harrows.

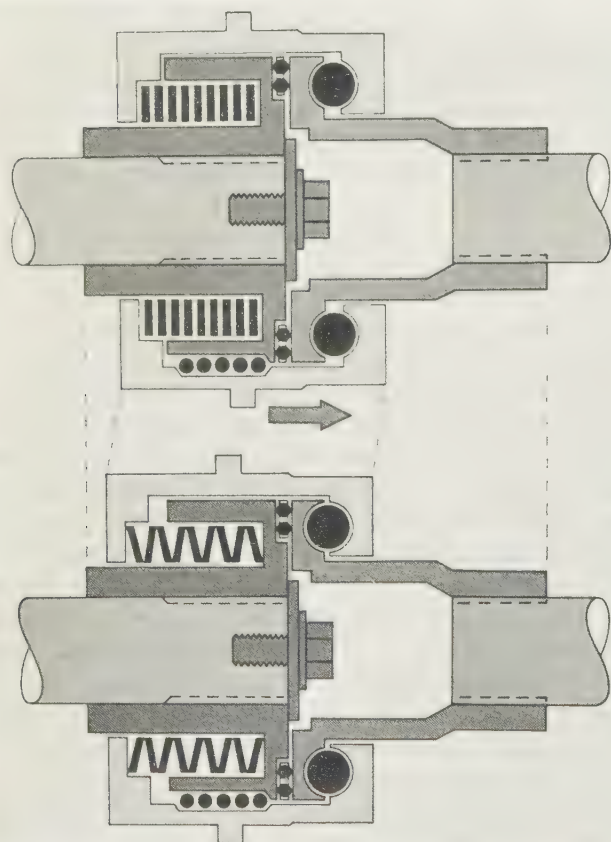


Fig. 2.24 Cross-section of torque-sensing ('Load Monitor') unit (Ford New Holland).

Left: transmission output shaft.

Right: pinion shaft to differential. Lower section shows low-torque position, with springs extended. Upper section shows springs compressed and the balls driving the coupling forced up the ramps, so moving the actuating lever to the right.

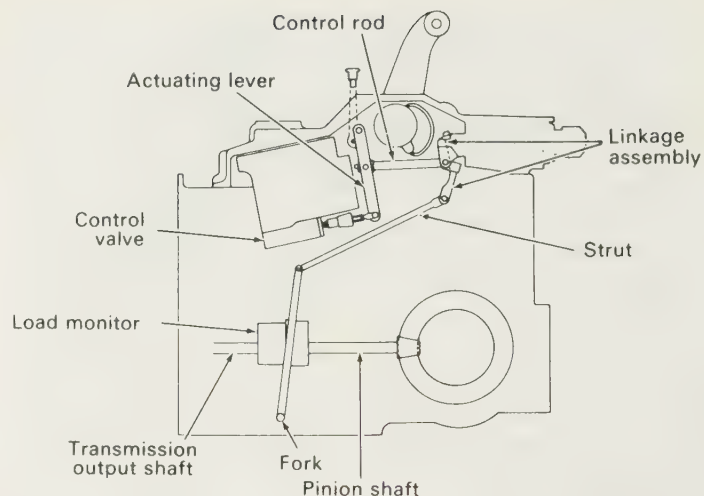


Fig. 2.25 Basic elements of torque-sensing ('Load Monitor') hydraulic implement control (Ford New Holland). Increasing torque moves top of control fork and control valve actuating lever to right. This allows oil to be pumped into lift cylinder(s) to raise implement and lessen load.

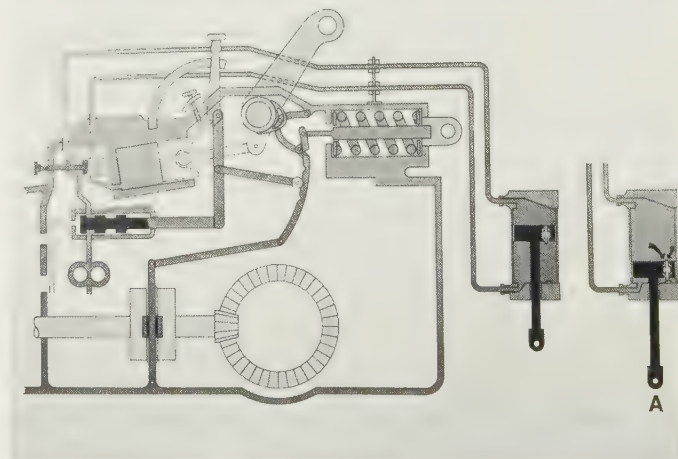


Fig. 2.26 Torque-sensing ('Load Monitor') hydraulic control of semi-mounted implement with rear-lift cylinder (Ford New Holland).

As external ram, A, moves down, oil displaced from external cylinder passes into internal ram cylinder. At end of external cylinder stroke (inset right) valve in piston opens and allows completion of lift by internal ram.

Electronic three-point hitch control

Electronic sensing in control of three-point linkage systems can expand control options and improve both the speed and precision of automatic systems. Advantages include elimination of inefficiency caused by friction, elasticity and wear of mechanical components; and flexibility in location of sensors and controls eases design problems. Elimination of movable rods and linkages facilitates sealing cab walls and is helpful where cab and implement are separated by a long distance.

Specialist component manufacturers working with tractor makers have developed draught control sensors in the form of sealed pins which couple the lower links to the tractor chassis and have their flexible cable leads designed to plug into the electronic control box. (Fig. 2.27). Similarly, a sealed position sensor can be conveniently located in direct contact with a suitably profiled cam on the main lift shaft. Action signals operate through solenoid valves, with pilot valves and automatic damping where needed. A mixture of draught and position control can be employed if required.

Tractor performance monitors: Electronic sensing can provide clear signals which assist drivers to make economic adjustments, and can lead to easy automation of some controls. Examples of commercial applications aimed at fuel-saving include a combined meter with two needles, one of which displays engine rpm via impulses from the alternator; the other indicates output via exhaust gas temperature. Optimum economy is achieved by keeping both needles in the green areas on the dial (e.g. Renault ECO-Control). It is a short step to using a microprocessor to provide automatic control when the 'economy' button is selected.

A comprehensive monitor includes a ground speed sensor operating on Doppler (radar) system, and a wheel speed sensor; the microprocessor, by comparison of the two signals, displays percentage slip when needed. An implement status switch indicates to the microprocessor when the implement is in work. The operator enters working width, and the display can provide spot work rate, total individual field areas worked and total area since area worked was last reset. The monitor enables operators to make adjustments to engine speed, gear used and load to secure optimum operation efficiency. Maximum recommended figures for wheel slip are about

15% for two-wheel-drive and 12% for four-wheel-drive.

An advanced 'Tractometer' suitable for fitting to any tractor make or model (RDS) measures forward speed by radar, drive wheel rotation, work rate, wheel slip and one shaft speed. Area covered is recorded and retained in the memory until the reset button is used. The required function is displayed in liquid crystal by use of touch-sensitive pads on the instrument dial (Fig. 2.28).

Accurate control of application rates in distribution of granular fertilisers presents problems similar to those discussed in Chapter 9 concerning application of chemical spray liquids. Direct control of application rate by microprocessor can be fairly easily arranged where the fertiliser is metered by a hydraulic drive to central metering feed rollers, as in many pneumatic distribution systems. A half-way alternative is a display system which enables the driver to adjust metering roller speed manually on slopes in proportion to forward speed. This can be useful to a skilled operator where it is not possible to maintain forward speed.

Hydraulic services

In addition to supplying power for the raising, lowering and control of the three-point linkage, the tractor hydraulic system is being used increasingly for other services. Modern high-powered sophisticated tractors make further use of the system within the machine to lessen the load on the driver. Actuation of the steering, brakes, gear changes and differential lock may all be from a single, if complex hydraulic system. Such a system is illustrated in Fig. 2.30.

The pressures hitherto employed in hydraulic lifts have varied widely according to the type of pump used and other practical limitations. There is, however, a trend towards the adoption of the British Standard working pressure of 2300 ± 200 psi (160 ± 14 bar). The disadvantage of the employment of different working pressures by different manufacturers is experienced when external jacking cylinders are employed on trailed implements and trailers, and when hydraulic motors are used.

External hydraulic services: The power available at the external hydraulic tapping or take-off point depends on both the rate of flow and the pressure of the oil. The flow rate is limited by the size and operating speed of the tractor's hydraulic pump but the power can be increased

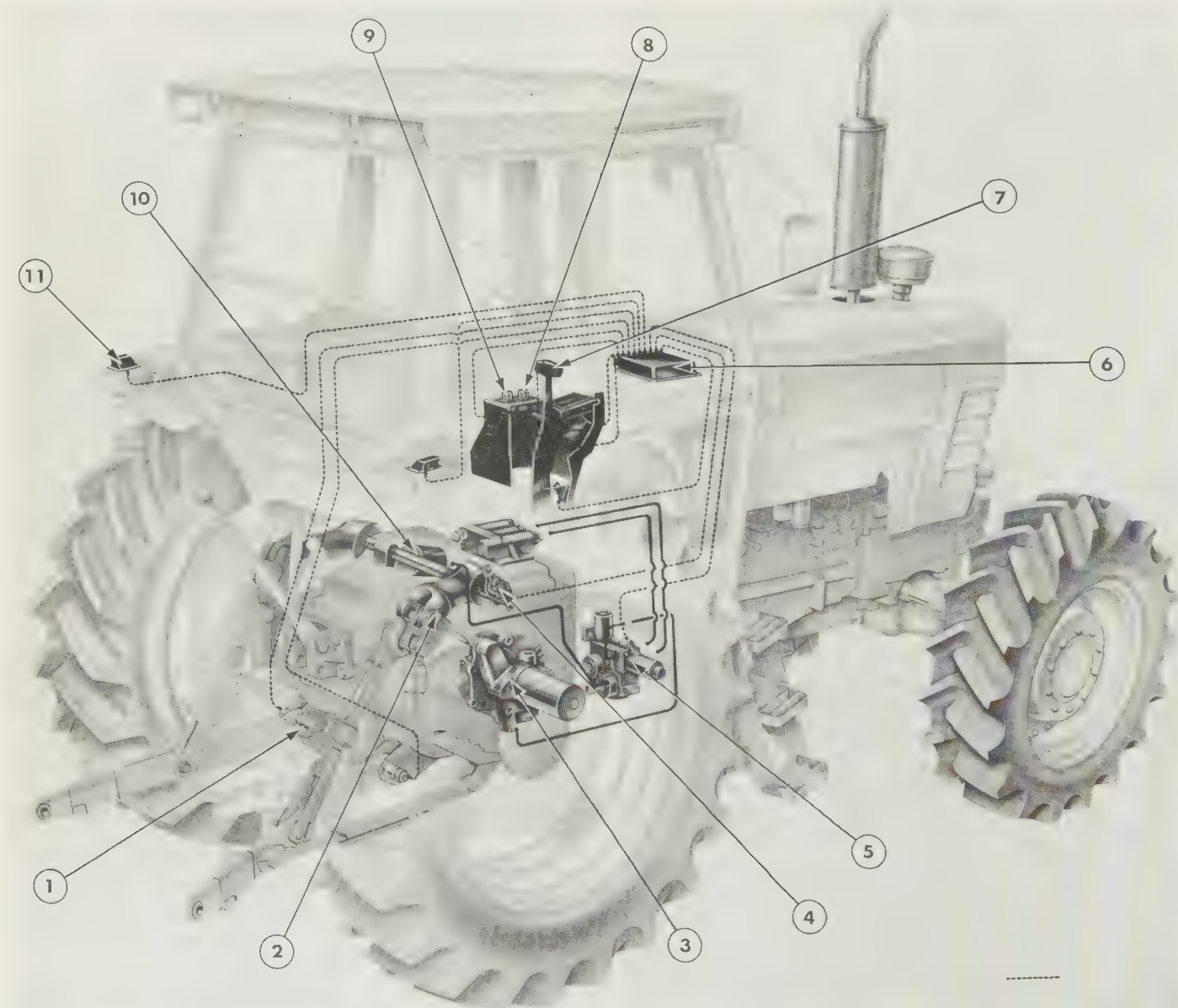


Fig. 2.27 Electronic tractor draught control, typical layout (*Ford New Holland*)

1. Load sensing lower-link pins; 2. Lift arms; 3. Hydraulic pump; 4. Position sensor; 5. Electro-hydraulic control valve; 6. Microprocessor; 7. Lift control lever; 8. Position/draft sensitivity control knob; 9. Linkage rate of drop control knob; 10. Hydraulic lift cylinder; 11. External linkage switches.



Fig. 2.28 Tractor 2 Performance Monitor (RDS)
Display (obtained by touch sensitive pad) gives (L to R) Speed; total area worked; trip area; spot work rate; wheel slip (%) and shaft speed (rpm). Either metric or imperial units can be selected by the operator.

by stepping up the relief valve pressure. On some tractors this can be as high as 3000 psi (207 bar) but it is more normal for it to be between 2200 and 2500 psi (152–172 bar). There are practical limits to the pressure that can reasonably be employed. Higher pressures, besides requiring tighter tolerances, impose greater loads on the pumps and pipework. Greater pressure losses across control valves are inevitable and this generates higher oil temperatures.

The hydraulic power available from a pump may be calculated (Imperial units) from the expression:

$$\text{hp} = \text{flow (gal/min)} \times \text{pressure (psi)} \times 0.0007$$

This is the power as the oil leaves the pump, but in practice losses occur because of friction and restrictions in the pipework, valves and couplings, as well as in the motor which converts the flow into usable power (see Table 2.3). In calculating the hydraulic motor power available from various makes of tractor it may be assumed that working pressure may be 90% of the relief valve figure, that at this lower pressure the pump delivery rate falls by 10% and that the efficiency of the motor may be 75%. This means that the overall efficiency of using hydraulic power from the external services of a tractor is likely to be little more than 65%, whereas mechanical

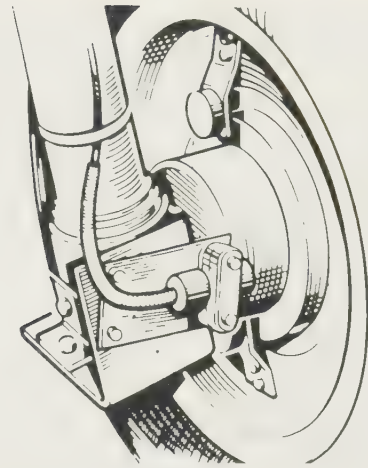


Fig. 2.29(a) Magnetic wheel speed sensor kit (RDS)
The encapsulated sensor is fitted in a shielded position adjacent to inside face of tractor wheel: strap-mounted magnets are fitted to the wheel itself.



Fig. 2.29(b) Doppler Radar 400 sensor kit (RDS)
A low-power signal is directed through the angled deflector to the ground. The reflected signal, mixed with a proportion of the transmitted signal, causes a change in frequency, proportional to the true ground speed, and is in no way affected by wheel slip.

transmissions should generally be over 80% efficient. For operations requiring only a little power, the lower efficiency is not significant and the convenience of the flexible drive easily outweighs the loss of power. The

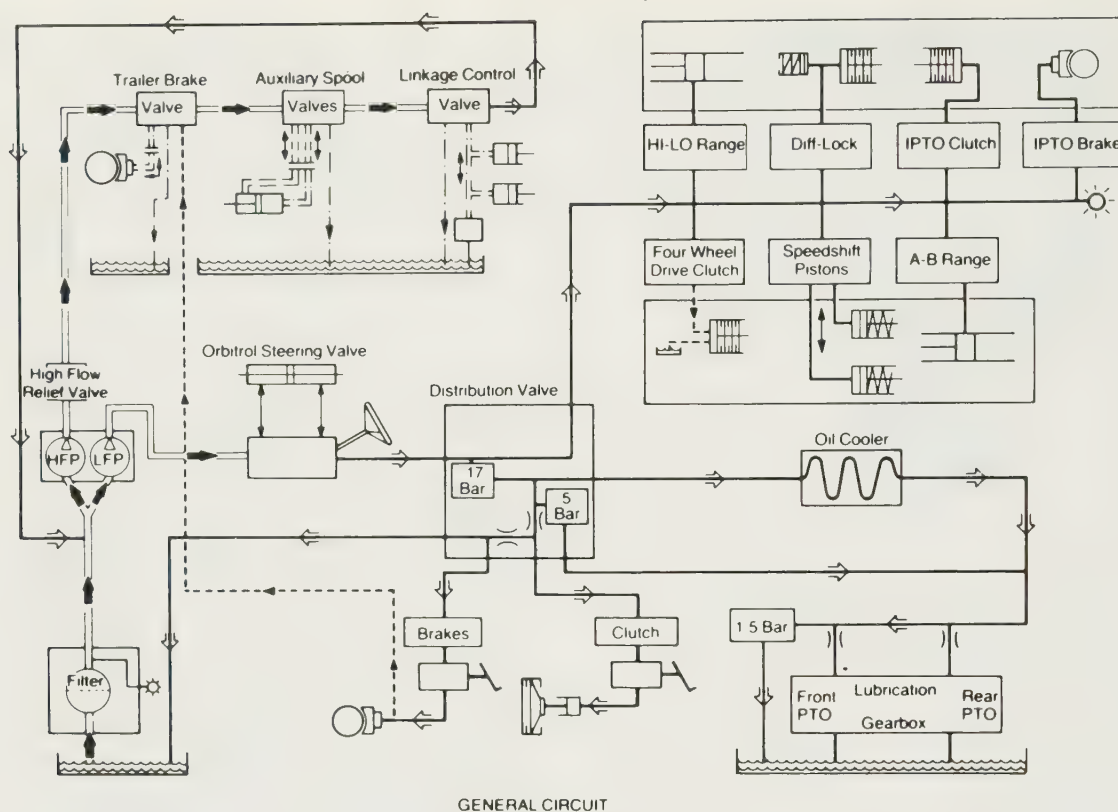


Fig. 2.30 Complex hydraulics system of open centre type combined with general lubrication and cooling. (Massey-Ferguson 3000 Series – early type)

Dual demand gear pump (bottom left) provides high flow (up left of diagram) and low flow (across to right). The gear-box and centre housing form a common reservoir. High flow side operates trailer brake, auxiliary spool valves and rear linkage

control. Low-flow side operates steering (first priority), and distribution valve supplies oil at a maintained pressure of 17 bar for: HI-LO range; differential lock; IPTO clutch; IPTO brake; four-wheel-drive; Speedshift pistons, and A-B range. Excess flow is used for lubrication and top-up services, and provides oil-cooling service.

Table 2.3 Approximate hydraulic motor power available at different flow rates

Flow rate at standard pressure (2300 psi) (160 bar)		Power assuming overall efficiency of 65%	
(gal/min)	(l/min)	(hp)	(kW)
3	13.5	3.1	2.4
5	23	5.2	3.9
10	45	10.4	7.8
15	68	15.6	11.7
20	91	20.8	15.6

upper limit for economic use of hydraulic motors from the tractor external services supply may at present be put at about 10 hp (7.5 kW). Beyond this any advantages over the normal mechanical transmission pto or belt pulley largely disappear. This conclusion is reflected in the types of tractor-mounted equipment currently being driven by hydraulic power, most of which have a fairly low power requirement. Where there are important technical advantages in replacing the mechanical drive, and power requirement is high, the normal solution is to provide a pto-driven pump on the equipment for the main drive, and to use the tractor's external services for the controls.

Filtration and reservoir capacities: With the convenience of connecting and disconnecting the self-sealing couplings to external hydraulic motors and rams, dirt inevitably sometimes finds its way into the hydraulic oil supply. It is therefore essential that tractor hydraulic systems are provided with first-class filtration devices. A further consideration is the quantity of oil used in operating the more complex hydraulically controlled implements. Where a number of external ram cylinders are to be operated, for instance on a hydraulic back-acting slew loader, the total quantity of oil in all the ram cylinders may amount to several gallons. The oil reservoir is normally the rear transmission housing, and care should be taken when connecting up such equipment that the correct quantity of oil is used and that the fluctuation in oil level in the transmission is within the limits allowed by the manufacturer.

There are two British Standards covering certain vital dimensions of hydraulic lifts and implement linkages: BS 1773:1951 which deals with lifts for trailed implements, and BS 1841:1973 which covers the widely employed three-point linkage method of implement attachment.

Power-lift linkage

Applications of external hydraulic services include raising and lowering operations on a vast array of implements and machines such as drills, root harvesters, etc. This section is concerned only with lift linkages that are directly attached to tractors, excluding specialised handling vehicles.

Desirable features in any implement control design include simplicity and cheapness; ease of attachment and adjustment; a reasonably uniform working depth and a quick entry of the implement to full depth; ability to penetrate hard land; ease of operation on side-lands; easy transfer of weight to the tractor's drive wheels where this is practicable, and stability of the outfit when the implement is raised on sloping land.

The following types may be distinguished:

(1) Tool-bar connected to the tractor by a parallel-motion linkage with depth control by wheels on the implement. Short parallel links have some important

imperfections in practice, and are now generally employed only for tools that work at shallow depths, such as hoes and drills.

- (2) Tool-bar connected to the tractor by a three-link 'free' system which gives a 'semi-parallel' motion, with a virtual hitch point near the front axle, and depth control by means of implement land wheels. Most tool-bars are allowed to float freely by using the lift rods in the position where telescopic action is provided.
- (3) Three-point linkage with a draught control system, often one in which the top link operates a spring-loaded control valve. For a given setting of the hand control lever the hydraulic system maintains a substantially constant draught on the implement. No implement depth-control wheels are used. 'Position' control may also be available, and draught control may be operated through the lower links. Various other facilities may also be provided. This is by far the most common and important linkage.
- (4) Three-point linkage with semi-mounted implements. Depth control at the rear may be by a simple depth-regulating land wheel; but increasing use is made of hydraulic rear-wheel depth control, which works in unison with the main draught-control system (e.g. Ford 'Load Monitor').
- (5) Three-point linkage for tracklayers. In a typical system (Marshall) the draught links and top link are mounted on a swinging drawbar which is pin-jointed under the centre of the tractor. This arrangement avoids the violent side-thrust forces that arise if a three-point linkage system is mounted directly on the rear of a tracklayer.
- (6) Front linkages are used for a wide variety of purposes, and it is not surprising that many different types are in commercial use. They include simple parallel linkages and three-point systems similar in design to standard rear three-point linkages with use of some standardised components such as Category 2 hitch pins for medium-weight equipment. A three-point system with check chains is often used in conjunction with a triangular-frame quick hitch of Accord A-frame type for equipment requiring a lift capability of up to about 1000 kg.

Developments involving use of high-powered four-wheel-drive tractors require much heavier lift capacities



Fig. 2.31(a) Front-mounted mower-conditioner with 2.8 m working width showing rigidly attached forward extension from the front three-point linkage enabling the use of a front-hinged suspension system to provide easy float on undulating surfaces. (Krone AFL 282 Z)

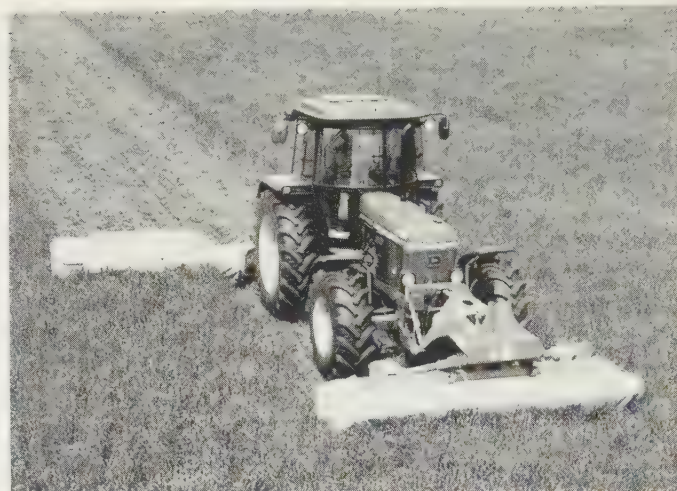


Fig. 2.31(b) Main application of front mower-conditioners is in conjunction with a rear-mounted model for effective use of a high-powered tractor when beginning to make wilted silage. (Bernard Krone (UK))

for implements such as ploughs, where more rigid mountings and stabilisers are needed, and automatic hitch claws are often fitted. Such heavy-duty front hitches may carry loads of 1500 to 3500 kg, and cater for pto powers of over 100 hp.

In rear three-point linkage systems the links of the two-axis hitch are made vertically converging, and if lines through the links are projected forwards, the intersection indicates the virtual hitch point of instantaneous centre of rotation. It should be noted that this is not a fixed point, but one which changes as the implement is raised or lowered. The linkage is so designed that the virtual hitch point is lower when the implement is in the raised position. This ensures that an implement such as a plough enters the soil at a steep angle of pitch, and settles down to an even keel when it reaches full working depth.

Three-point linkage hitches have links which converge in a horizontal as well as a vertical plane, and the implement is either free to swing about a virtual hitch point that is well forward, or is restrained by check chains. When the implement is allowed to swing and the tractor turns, the implement tends to follow on a curve that lies inside the tractor's path. If, however, the implement is fitted with a fin, which tends to make it run in a straight line, this tendency can be corrected.

The advantages and disadvantages of the various systems of implement attachment are the subject of controversial claims by manufacturers. As already indicated, the subject is a complex one, but the chief factors that a farmer needs to consider are (a) ease of attachment of the various implements; (b) low cost of the linkage and of the individual implements; (c) efficiency of the devices for securing 'weight transference' when engaged on heavy work; and (d) ease of operation, and efficiency of depth control methods.

The attachment of heavy mounted implements to the tractor three-point linkage is a fairly simple one-man operation provided it is gone about in a logical way. The most important part of the operation is to position the tractor square and in line with the centre of the implement. This is made easier, of course, if the implement has been previously parked on a level piece of ground. Most modern tractors have an adjustable top link, and this can be attached first and used to make the final fine adjustment of distance between the tractor and implement to allow the lower links to be fitted.

With high-power tractors built to carry implements weighing over 1 ton, the linkage is heavier and more difficult to manipulate by hand. The manufacturers have recognised this and have added additional refinements to

aid the operator when coupling up to an implement, e.g. telescopic lower links. This allows the link to be extended to fit on to the implement hitch pins by lifting the lock pin. After attachment, the tractor is gently reversed and the implement raised and lowered until the lock pins snap into place.

A sensing system of advanced design includes an external hydraulic control unit mounted on the rear fender. This allows the positions of the lift arms to be accurately adjusted by the operator while standing in a safe position behind the tractor (e.g. Case-International, etc.).

Quick hitches

A basic need in coupling an implement is to have an

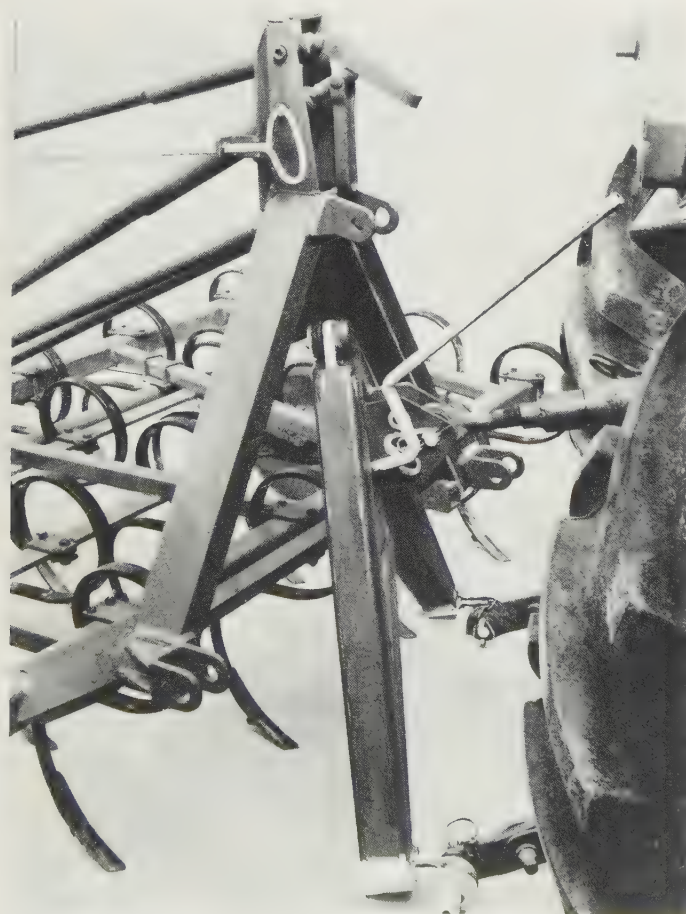


Fig. 2.32 A-frame quick hitch showing matching triangle of channel steel built into implement headstock. (Ferrag/Accord)

automatic pick-up mechanism which the driver can operate without leaving his seat. The American standard hitch ASAE S 287-1 (shown in Fig. 2.21) is a simple attachment for the tractor which requires the minimum modification of the standard implement hitch to accept it. The frame in the shape of an inverted U remains connected to the three link ends of the tractor. Three hooks protrude rearwards from this coupler in the positions of the two lower and one top link pins of the implement tripod. The tractor is reversed to the implement until the lower hooks will, when raised by the linkage, connect with their respective pins. Before doing this, however, the top link may require some adjustment, which on some tractors can be done from the seat.

With another type (Walterscheid) the lower links are connected by a more flexible spacing-frame and the catching hooks are guided into position by cones fitted to the hitch pins on the implement. The hook on the top

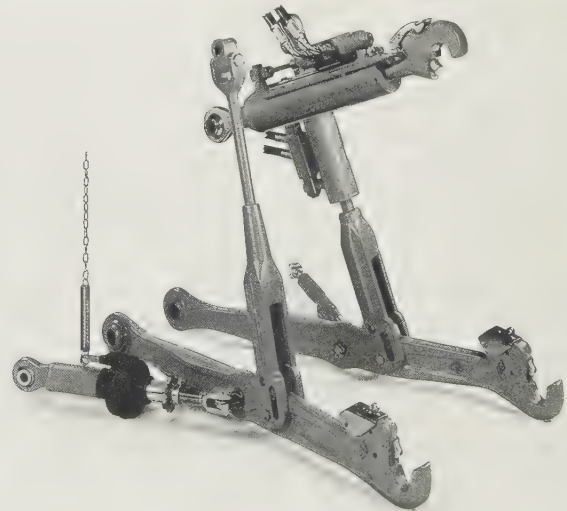


Fig. 2.33 European three-point linkage quick hitch, WKS. The complete tractor/implement attachment system makes it possible and safe for an unaided driver to hitch tractor to implement from the driver's seat. The system includes an automatic lateral stabiliser seen attached to the left lower link. The other lower link is guided by a pre-loaded lateral spacer spring set to correct width for the implement. Right-hand lower link and top link are *both* hydraulically adjustable in length, independently of the main tractor lift system. Both are based on use of twin type non-return valves. All hooks are self-locking and can only be released by use of the opening lever provided. (Hardy Spicer Drive Line/Walterscheid WKS)

link can be attached to a telescopic arm which replaces the normal adjustable link. The top link is connected first. The tractor is reversed to shorten the link, and when the lower links are in position the linkage is raised to engage. The implement is released when the linkage is lowered and release cords attached to each hook are pulled. This hitch is designed for use with an automatic pto-coupling which requires special adaptors to be fitted to both the pto and the power input shaft on the machine.

Another type involves the use of two triangular frameworks: one fitted to the tractor linkage, the other to the implement. The tractor frame fits inside the implement triangle and is held in place by a latch operated by a lever from the tractor seat. This type of coupler allows a greater degree of misalignment of the tractor and implement, but the implement is generally displaced rearwards from 100–150 mm (4 to 6 in) unless the implement triangle is built in as the implement headstock, rather than being added to an existing three-point linkage headstock.

Four-wheel-drive tractors

A four-wheel-drive tractor that is to have appreciable advantages for difficult conditions must possess front wheels that are not too small, have a traction-type tread and carry an appreciable proportion of the total tractor weight when the tractor is at work. Tractors with medium-sized front wheels tend to be somewhat more versatile than those which have all four wheels of the same size. The front wheels of four-wheel-drive tractors are now invariably power-steered, but the turning circle without braking naturally tends to be a little smaller with those having smaller front wheels. This type can be effectively used for work such as forage harvesting, root harvesting, etc. In advanced designs power flow to the front axle may be controlled by a mechanically engaged and hydraulically disengaged multi-disc clutch. In the absence of either electric or hydraulic power this clutch automatically engages, forming a solid link between wheels and engine, and providing four-wheel braking by means of the engine compression. Some tractors with a high-capacity closed-centre hydraulic system have hydrostatic front-wheel-drive. The wheel motors have a limited power input needing no more than 75% of maximum oil flow, a proportion nearly always available in draught work where

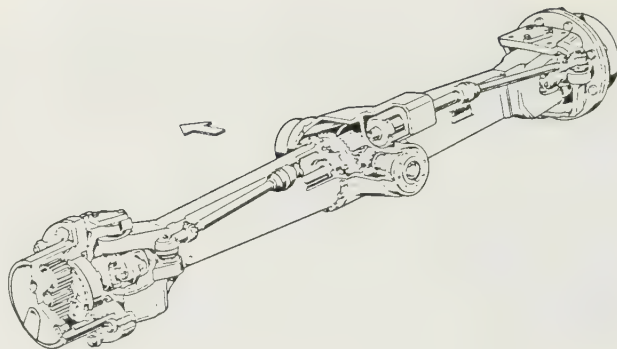


Fig. 2.34 Tractor steering axle with limited slip differential and integrated steering cylinder. For detail of differential and practical application see also Fig. 2.35. (Z-F APL 300 Series)

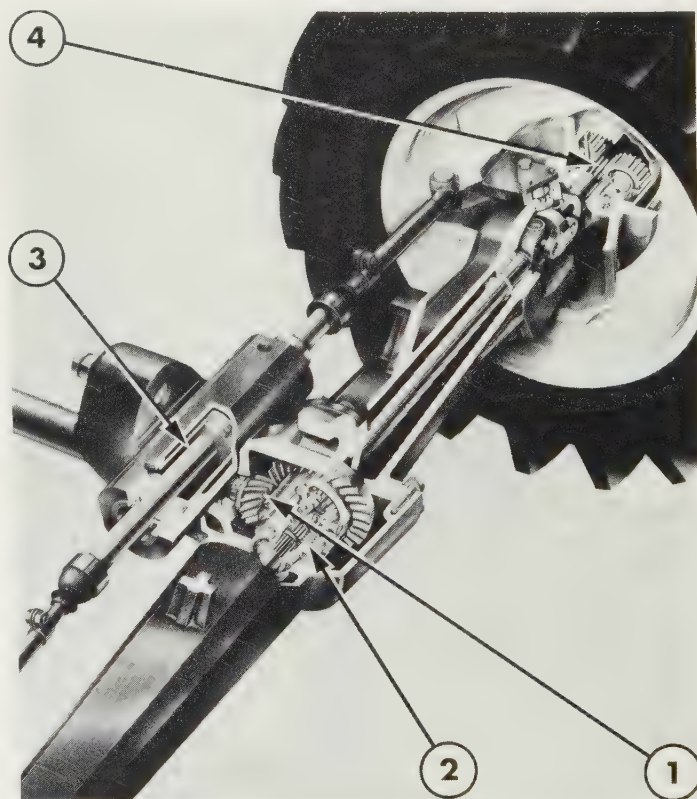


Fig. 2.35 Application of compact limited slip differential front-wheel-drive with integrated steering cylinder to 150–200 hp range (Ford New Holland Series 30 Six-cylinder).
1 Central drive pinion, 2 Limited slip clutch, 3 Steering cylinder, 4 Speed reduction epicyclic gear set.

the front-wheel-drive is required. In some mechanical drives engagement automatically takes place when rear-wheel slip exceeds about 6%.

With tractors of conventional design there are normally good reasons for disengaging four-wheel-drive when travelling on hard, level roads. To secure best performance in field work the front axle tyres are usually driven slightly faster than the rear. Disengagement of front drive on the road helps to reduce tyre wear and to avoid excessive transmission wear due to 'transmission wind-up'.

When specialist transmission manufacturers developed mechanical front-wheel-drive axles both 'no-spin' and 'limited slip' types were evolved and taken up by tractor manufacturers. A 'no-spin' type was found in practice to be not completely safe when used by inexperienced operators, and with the rapid development of use of electro-hydraulic engagement and disengagement, use of simple automatic mechanical engagement types was quickly superseded by hydraulic power operation types on safety grounds. Increased safety has been given priority in development of automatic engagement and disengagement of both four-wheel drive and differential lock on tractors with computer assisted automation by designs which ensure that the tractor is always in the safest operational mode.

There are other design factors concerning which conflicting claims are made. A steering angle of about 50° is desirable in large as well as small tractors; with large four-wheel-drive vehicles the front wheels are large, and in some designs the tops of the kingpins may be inclined rearwards about 12° to provide a 'castor-action' enabling the lower part of the inner front wheel to run beneath a chassis member at full lock. Other designs aim to keep the wheels in a vertical plane during turns, so that the heavy loads and side thrusts are borne on the full width of the tyre tread.

Pivot steering is often used on very high-powered tractors, especially eight-wheel types. In a typical arrangement, the tractor chassis is divided into two rigid parts, the engine and controls being carried on the front axle unit, and the normal three-point linkage and drawbar on the rear. These two components are connected through a centrally located pivot, and steering at a lock up to 42° is effected by a double-acting hydraulic ram which moves the two parts about the pivot. The front axle unit can tilt independently of the rear through an angle of up to 30° . The weight distribution gives a static loading of about



Fig. 2.36 Eight-wheel-drive tractor with articulated frame steering (*Massey-Ferguson 4880*) seen breaking stubble with level-lift deep cultivator (*Cousins*). Centrally located pivot pins and a horizontal trunnion assembly allows a limited degree of rotation between the front and rear parts over ground undulations. Electronic lower link sensing may be employed for three-point-linkage equipment.

68% on the front axle, resulting in about 50:50 loading when weight is transferred to the rear axle by mounted implements. The transmission system has universal joints at the pivot point. The cab of high-powered tractors with articulated chassis is usually on the front half. Another type has the cab at the rear and the engine well forward on the front half so that 66% of static load is on the front axle. An advantage is compatibility of production and operation of the rear end with tractors having 'conventional' steering. Disadvantages of pivot steering include some complexity in mechanical transmission of power round the articulation axis; hydrostatic transmission used on some power frames avoids this problem. There is also the possibility of imposing excessive side strain on mounted implements, and some difficulty in correcting



Fig. 2.37 Fendt 380 GT tractor on high-clearance wheels with large spray tank front mounted and rear-mounted sprayer. (RAU)

for side-slip on steep slopes. One high-powered type with equal-size wheels, has a non-articulated chassis and 'all-wheel' steering (e.g. Case). This provides four steering options, viz. front wheels only; rear wheels only; 'co-ordinated', with front and rear moving in opposite directions to accentuate the turn; and 'crab', with front and rear moving in the same direction. These more complex steering options are useful mainly for handling work: large sideways movements are not normally desired in field operations.

Most very high-powered articulated-steer tractors (e.g. over 200 hp) are fitted with eight tyres and are so wide (over 2.75 m) that their use on the highway in Britain is subject to specific restrictive 'use' regulations.

'Systems' tractors with load platform

With adequate engine power and four-wheel-drive from well chosen wheels it can be economic to provide for mounting and power-driving equipment at both front and rear, and to fit a load platform to assist operation of drills, sprayers and fertiliser distributors. Over-drive gears, four-wheel braking and a chassis with springs and shock absorbers allow high road speeds with safety, and reduce the strains on spray booms operated over rough surfaces at 8–15 km/h. There are many combined operations which can be done better simultaneously from both technical and economic aspects.

A vehicle of economic design tends to have differences between front and rear which depend mainly on location of engine and cab; the differences can be sufficient to make it worthwhile to provide for long-term work in reverse. German manufacturers have shown that this can be neatly done by having a purpose-designed cab and a console comprising seat and driving controls which rotate as a single unit through 180° after release of one locking device (e.g. M-B-trac). Such features make it practicable to use the vehicle in reverse for such duties as operating a high-capacity mounted forage harvester or a heavy-duty loader. Vehicles of this general type clearly provide a basis for development of many types of self-propelled machines in addition to those, such as contractors' sprayers, which are already well proved.

High-speed tractors

An outstanding 'systems tractor' series which has been developed over a period of 40 years (Mercedes Benz Unimog range) has throughout the development been based on the concept of a four-wheel-drive vehicle having equal-sized wheels, with clearance to work in fairly tall crops and rough-terrain conditions, and a speed and draught range providing for work from deep cultivation, or trench digging using a creep-speed option, plus authorised public road transport in many countries at speeds up to 70 km/h. The provision for high-speed road transport has required a chassis suspension with coil springs and telescopic shock absorbers front and rear, with dual circuit air over hydraulic disc brakes and spring-loaded parking brake on the rear wheels, thereby satisfying legal requirements comparable with those for high-speed road transport trucks. The comprehensive specification tends to make the system non-competitive where the high-speed features are not required. The main power units range from 75 kW (U-1000) in stages to 125 kW (U-1700). Current options include an on-board computer system with monitoring and display of a wide range of performance functions, including slip display, area worked and work rate, and pre-selected pto rotation speeds, front and rear. The power lift linkage control system includes pressure control at both front and rear, with remote control on-off switches on both sides. Working positions of equipment are automatically re-set after lifting at headlands. The demand from farmers for high-speed road transport has steadily increased throughout Western Europe with greatly increased work rates from a wide range of harvesting machines for cereal, forage and root crops; and many new models with high speed capabilities are expected to be studied with interest by progressive users.

The JCB high-speed tractor introduced at the Smithfield Show in 1990 is designed to fulfil all of the normal land-work functions of a large-medium powered four-wheel-drive farm tractor with a new-design Perkins 1000 Series engine of 93 kW (125 hp) or a more powerful turbo-charged model of 107 kW (145 hp) capacity. The transmission has 18 forward and six reverse gears with full synchromesh: a top speed of 40 mph is available for use with a high-class tandem wheel trailer of 14 tonnes laden



Fig. 2.38 High speed 4-W-D tractor with high speed tandem wheel trailer designed for road speed 40 mph with pay load up to 14 tonnes. (JCB HMV)

capacity fitted with braking and suspension to meet EC regulations. The basic tractor model aimed primarily at field work involving high-traction pulls where needed is fitted with adjustable-track-width bolted wheels 16.9 R30. With these wheels maximum road speed is restricted to 32 km/h (20 mph). The high mobility vehicle (HMV) specification provides for welded wheels and its standard tyre equipment is 445/70 R24 or 495/70 R24 at 1830 mm (72 in) track width. Braking type for all vehicles is single caliper outboard discs on all four wheels with operation air over hydraulic to EC truck specification. For road haulage the HMV can efficiently use a twin axle trailer with twin line air brakes at road speeds of just over 40 mph. A main design feature common to all JCB HMVs is all-round suspension of a type which is sturdy enough to give a greatly improved ride for the driver on rough agricultural surfaces and also enables work such as crop spraying to be done better. Coil springs and dampers at the front and hydro-pneumatic levelling with gas springs at the rear are the main elements involved, and are a part of the legal requirements for high-speed road travel.

In the cab, items such as tinted glass, laminated wind-screen and electric windows plus a passenger seat are standard, with optional items including full air conditioning with carbon filter and de luxe swivelling driver's seat.

Provision is made for a 2.5 tonne rear deck load. Standard (Cat 3) heavy duty three-point linkage and dual standard pto are available at front and rear. Rear linkage

lift capacity is 4 tonnes, subject to front counter weight if needed.

Self-propelled tool-bars

Self-propelled tool-bars have been developed mainly with the aim of doing really accurate work with drills, hoes and band sprayers using a one-man outfit. The engine and transmission are compactly arranged over the rear driving axle. Machines of low engine-power have tended to go out of production, and modern equipment is usually of a more multi-purpose character, with an engine of up to 50–70 hp (37–52 kW). When such a self-propelled tool-bar is used for draught purposes or with rear-mounted tools it is usually fitted with a transport box to help in providing the necessary amount of weight at the front.

Multi-purpose power frames

Multi-purpose power frames have been developed in many countries with the objective of using them as the power units for a variety of harvesting operations. None has achieved continued acceptance. Combinations of operations which have reached the stage of commercial marketing have been forage harvesting and harvesting cereals and grain maize. Other crops worked on with limited success include sugar beet and potatoes. Technical success in comparison with use of specialist self-propelled machines is always greatest where a restricted range of operations is attempted, and where technical differences between crops are not a major difficulty – thus it is fairly easy to cater for two types of distribution operations such as spraying and fertiliser distributing.

Technical developments such as hydrostatic transmissions, electrohydraulic control systems, and the application of electronic sensors and microprocessors have made it possible to overcome many of the earlier difficulties; but factors which are likely to preclude any rapid development of use of multi-purpose power frames are the need for gathering and processing equipment specific to individual crop types and variations; the advanced design needed to make equipment changes really easy; and the fact that the need to use the power frame for an additional operation can make it less valuable for the purpose for which it was primarily designed or chosen.



Fig. 2.39 Fendt medium powered four-wheel-drive tractor typical of 1990's trends. The front load platform is capable of carrying a complete 190° slew 8 m reach flail hedge cutter, but is shown here with Accord DF 3 metre Turbo-drill T 300A which has its coulter-bar attached close behind a vertical-axis 3 m power harrow. The seed is carried in the front-mounted hopper, with spiked metering drive wheel and hydraulic drive centrifugal fan conveying metered seed via mushroom seen at rear to the coulter. A wavy-edge crumbler roller levels the between-wheels strip. (*Fendt F380 KOMPACT GT*)

Low-ground-pressure vehicles

Tyres

Commercial low-ground-pressure (LGP) vehicles have to provide successful compromises between load carried, tyre or track size, and soil conditions, especially softness and moisture content. There are such wide variations in soil softness and resulting compressibility that most discriminating users need more than one type of wheel equipment, whether the vehicle is a tractor or a more specialist self-propelled distributor. Limitation of sinkage into soft soils necessitates restricting load per unit of contact area of the wheels during work. The pressure on soils is not easily measured because the 'foot-print' area increases as load-carrying wheels sink, and tread width varies with air pressure in the tyre. The load of an LGP vehicle is carried mainly by the air pressure in the tyres. Radial tyres are preferable, but even with these the stiffness of the tyre walls also has some load carrying capacity, sometimes called the carcass pressure; for conventional tractor types of semi-LGP type it may be from



Fig. 2.40 High clearance, lightweight self-propelled sprayer/distributor with 24 m alloy booms designed for easy demounting to fit alternative applications systems. (*Willmot Lightspray*)

about 3 to 7 psi (0.2–0.5 bar); it is typically very low for the soft-walled tyres of true LGP vehicles, where a *total* ground pressure of about 5 psi (0.345 bar) may be the aim. From a practical agricultural viewpoint, the aims for tread patterns and overall profiles should include avoidance of sharp edges and deep lugs, which can severely harm young growing crops. When using LGP tyres on rear tractor wheels the effects of front wheels should not be overlooked.

General characteristics

Requirements depend on the main types of work to be done and the amount of travel on public roads. Vehicles primarily for agrochemical applications need to be able to maintain a constant fairly high forward speed (e.g. 8–15 km/h) during work; this requires adequate power on hills and an infinitely variable speed hydrostatic transmission can be worth consideration. An independent suspension can improve spray boom stability and evenness of spread of granule distributors. Front and rear wheels should track on headland turns; pivot steering can be suitable for four-wheeled vehicles. The conflicting needs of LGP work in late autumn and high crop-clearance work in midsummer can be economically catered for by buying both LGP and row-crop wheels. The latter will be suitable for long road journeys. Essential features of

overall design are lightness with strength, and ability to change both wheels and working equipment quickly and safely.

Motor-cycle based all-terrain vehicles (ATVs)

Rugged low-ground-pressure shaft-drive tricycles and four-wheeled ATVs have been found valuable on farms both as a multi-purpose work-horse on rough hill land and for distributing agrochemicals on soft wet arable land. A purpose-developed machine (e.g. Honda 250) which has been successfully equipped for a wide range of duties has a four-stroke engine with good torque characteristics developing up to 20 hp; a standard five-speed

and reverse gearbox incorporating a super-low ratio first gear; long-stroke front and rear suspensions, the rear with adjustable hydraulic damper; medium-sized load platform at rear and small one at front; drum brakes front and rear, the latter fully sealed; and a trailer hitch. An essential feature is the wide balloon tyres with tread pattern designed for carrying reasonable loads and for providing traction to pull a trailer or equipment on soft surfaces without serious damage to the soil or to growing crops.

Big four-wheel-drive ATVs now occupy an important place in the machinery organisation on many large-scale arable farms on account of their ability to spread fertiliser top dressings or to spray on cereal crops at a time when heavy soils lie wet, and more powerful conventional tractors, even if equipped with LGP tyres, cannot work without serious wheel damage to soil structure and to growing crops. An ATV with engine of about 350 cc, four-wheel-drive and four large-diameter LGP tyres, coupled with a well designed spreading/spraying vehicle similarly equipped with two or four large LGP tyres is able effectively to treat a 12 m bout width for both types of operation. Working speeds of 8–10 mph (13–16 km/h) are practicable on straightforward work: quality of the work done can be high: and ability to work to top-dressing time-tables and to avoid deep ruts in tramlines can result in better yields and less trouble with future cultivations.

Many farmers when distributing fertiliser aim to carry up to a 250 kg (5 cwt) load, usually applying 125–150 kg/ha (1 to 1.25 cwt/acre). They can cover up to 40 ha (100 acres) in a good day, with the fertiliser close at hand. Most users report that on wet soils spring work has been revolutionised where a well-equipped four-wheel-drive power unit and matched vehicle were chosen.

Tracklaying tractors

Tracklayers are designed to secure good adhesion and transmit high drawbar pulls in difficult conditions, where wheels fail to secure an adequate grip on the soil. They are particularly suitable for use on steep hillsides, on heavy land, on fen land where particularly deep cultivations are required, and in all conditions where running wheels over the land may harm the soil structure.

The track may be looked upon as a continuous rail made up of links and supported by the track plates. The



Fig. 2.41(a) Powerful 'mini-tractor' (244 cc air-cooled oil injection) with automatic variable transmission pulling four-wheel LGP vehicle equipped with engine-driven fertiliser distributor. (*Polaris Trail-Boss 4 x 4 with Logic System 40 vehicle*)



Fig. 2.41(b) Four-wheel-drive ATV with engine driven 600 l capacity sprayer on two-wheeled chassis carrying 12 m spray boom. (*Kawasaki/Logic/Allman 'Cropguard'*)

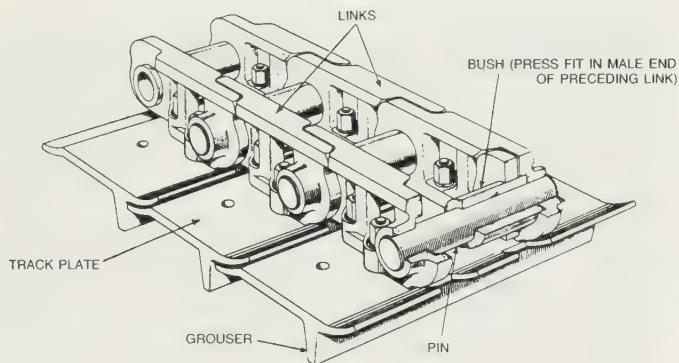


Fig. 2.42 Track of tracklaying tractor.

tractor driving sprockets gear with the links of this rail, and the tractor rolls along it on the track rollers. The track is picked up after the tractor has passed over it and is relaid continuously. It provides a large area of contact with the ground and is eminently successful where adhesion is difficult. Average ground pressure beneath the tracks of a typical medium-powered agricultural tracklayer with foot-print 1.88 by 0.4 m (74 by 16 in) is about 6.4 psi (44 kN/m²). Comparable pressure figures for wheeled tractors with normal tyres are from two to four times as high.

The track itself usually consists of a series on links and ground-plates, coupled together by pin joints.

The main defects for an agricultural user, whether farmer or contractor, are the wear that occurs at the pin joints and the need to use a well constructed heavy-duty low-load trailer to transport the tracklayer and its cultivation equipment on public highways. Developments in construction and use of reinforced endless rubber tracks have substantially revolutionised prospects for technically and economically successful movement along public roads, while maintaining or even improving field performance in adverse soil and crop conditions. It is therefore logical to examine some other basic factors of agricultural tracklayer designs.

The primitive clutch and brake steering system continued to have adherents long after developments in military tank designs had indicated that a power-operated controlled differential system with infinitely variable speed to the two tracks could probably be worthwhile, and there gradually emerged an obvious need for a three-point-linkage system suitable for general cultivation implement operation. About ten years of development work

by Track Marshall led to a linkage with a front pivot joint located just forward of the centre of gravity of the tractor; and though the complete design was complex at the implement end, the general principle of applying the substantial force of the mounted implement's weight low down on the tractor frame and well forward has been found satisfactory.

Improvements by Track Marshall in their controlled differential steering system came to fruition with power operation, manual use of a single joystick, and a device for occasionally varying the speed ratio to the two tracks from the driver's seat to suit the operational conditions. The combination justified an RASE Silver Medal award in 1981. Tracklayers are regularly expected to be driven for long hours with short meal breaks, and give value for investment in good ergonomic design, with regard also being paid to effective air filtration, control of temperature, limitation of physical shocks by use of oscillating tracks, effective shock absorbers between cab and chassis, and a good suspended seat with swivel release.

Effective control of the cab atmosphere makes it particularly worthwhile to complete protection of the operator by generous use of sound insulation cab linings to ensure that noise levels at the driver's ear do not exceed 80 dBA in view of the long working days.

The potential versatility of tracklayers has been revolutionised by the advent of the 201 kW (270 hp) Caterpillar Challenger 65 with its tracks consisting of endless rubber belts with continuous flexible steel cable bonded into the rubber (Mobil-trac system). Each of the 6.22 m long rubber belts has 72 rubber grousers to provide traction; and spring-loaded track tensioners connect the whole idler system with the front of the main frame. Drive to the tracks is by pulley wheel having a thick rubber surface with 13 mm high diagonal lugs to enhance friction. There are two large pneumatic front idlers and eight mid rollers on each track, and hydrostatic steering via differentials is operated by a car type steering wheel. A full power shift gearbox provides six closely spaced gears in the 6–11 km/h tillage speed range. A road speed up to 18 mph is allowed on the highway.

With track foot-prints 622 mm wide and 2700 mm long, soil ground pressure claimed is 0.4 kg/cm² (5.5–6 lb/in²). Built-in electronic instrumentation includes a radar gun for true ground speed measurement, and practical tillage trials have shown slip figures as low as 4% at maximum power. A pressurised air-conditioned

ROPS safety cab with filters provides a dust-free atmosphere; and a noise test level of 77.5 dBA at the driver's ear. Capital cost and time for experience to be gained on track life may restrict the rate at which UK farmers can justify taking up this important agricultural engineering development.

Like the rubber-tracked Caterpillar 65, the rubber-tracked Track Marshall TM 200 introduced at the 1990 Royal Show justifies mention of the main features. The endless rubber 'Elastomeric' tracks have integrally moulded rubber lugs on the outside to provide a grip on the soil, and rubber teeth on the inside which are positively driven (non-friction) by large diameter steel rear sprocket wheels. Ground contact dimensions of each track are 2400 mm (98.5 in) by 510 mm (20 in), and estimated pressure on the soil by the 21 000 lb tractor approximately 5.5 lbf/in². Pneumatic-tyred rubber front idler wheels provide automatic hydraulic belt tensioning via the centre pivot spring suspension axle. Four pairs of load-sharing rollers on each track are supplemented by an air spring cushion. A system of positive track guides keeps the tracks running true. A 6-cylinder turbo-charged diesel engine provides 149 kW (200 hp) at rated speed.

Transmission is by 3×2 speed power shift which with overlapping range gives 13 forward speeds from 0.29 to 13.4 mph. Final drive is hydrostatic with outboard planetary reduction units.

An infinitely variable self-centring hydrostatic steering system is operated by a steering wheel. Normal steering slows the inner track, with power delivered to both tracks: the further the wheel is turned at low speeds the greater the difference in speed between the two tracks: at very

low speeds the tracks can counter-rotate and result in pivot steering. The closed centre hydraulics system operating at 90 l/min and 170 bar provides an implement lift capacity of 6500 kg at the Category 3 three-point linkage, the drawbar of which can be fully swinging or locked. The structural steel cab with tinted and laminated glass, air filtration, heating and air conditioning is attached on four fully insulated rubber mounts and can be tilted sideways by hand-operated built-in hydraulic jacks for easy access to the important engineering features below the floor.

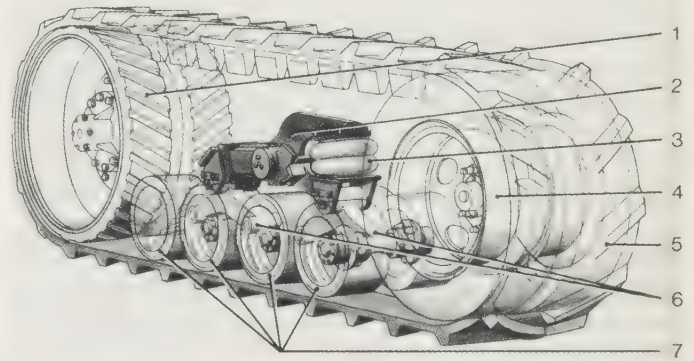


Fig. 2.43(b) Perspective view of main features of final drive wheel, suspension features and reinforced rubber track of Caterpillar Challenger 65.

1 Drive wheels; 2 Major bogie; 3 Air spring; 4 Pneumatic idlers; 5 Mobil-trac belt; 6 Minor bogies 7 Mid wheels.



Fig. 2.43(a) Working picture of Caterpillar Challenger 65 stubble breaking in Eastern England.



Fig. 2.43(c) Marshall TM 200 rubber-tyred tracklayer.

Half-track equipment

The limitations of rubber-tyred wheels have caused considerable interest in 'half-track' assemblies which may be fitted in place of or around the rear wheels of general purpose tractors. The object is to provide an outfit which is capable of overcoming difficult conditions and will provide a substantial drawbar pull in circumstances where any type of wheel would be unsatisfactory.

One type of half-track fits over the rear wheel tyre and is supported by an idler wheel mounted between the front and rear wheels. One of the advantages of this type is the ease with which the tracks can be fitted or removed from the tractor. The improvement in grip may be sufficient to make the difference between ability to keep going and much waste of time due to getting bogged down in slippery conditions. It should, however, be appreciated that it is not usually practicable to do continuous heavy work with half-tracks of this general type. Maximum drawbar pull in slippery conditions with such half-tracks fitted is likely to be less than that obtainable from pneumatic-tyred wheels where adhesion is good. Other types of half-track of roughly equilateral triangular form have been successfully used on combine harvesters for work in rice: but on tractors capital cost and ease of fitting have tended to restrict demand mainly to wide LGP tyres or twin wheels.

The development of rubber full-track tractors has naturally revived interest in half-track machines with rubber



Fig. 2.44 Rubber belt half-tracks used on Massey-Ferguson 3080 for high-speed power drive seedbed preparation. (Colmant Cuvelier Kitco tracks)

half-tracks wrapped round existing pneumatic-tyred tractor drive wheels and the pneumatic tyred idler wheels located just ahead of the tractor drive wheels and forming part of a well designed track tensioning system (e.g. the French made Colmant Cuvelier KITCO tracks, Fig. 2.44).

Narrow-track tractors

Narrow-track tractors are of interest to growers of fruit and hops who frequently need to pull a heavy spraying machine as well as to carry out ploughing and other tillage operations. Such tractors with engines of 25–45 hp (19–33 kW), may have overall dimensions as small as about 1 m wide and 1.3 m high.

Lower-powered tractors of conventional design and small overall dimensions are often described as 'compact' tractors. Most lie within a power range from about 13–27 hp (10–20 kW), and sizes above about 12 kW can often be supplied with four-wheel-drive. Some of the smaller sizes (e.g. in the Ford Series 10 range) can be supplied with a type of front-wheel-drive employing inclined double bevel-gear drives at the outer ends of the horizontal drive shafts. This provides a front axle with a good clearance even when using quite small steering wheels suited to the low power (See Fig. 2.45).

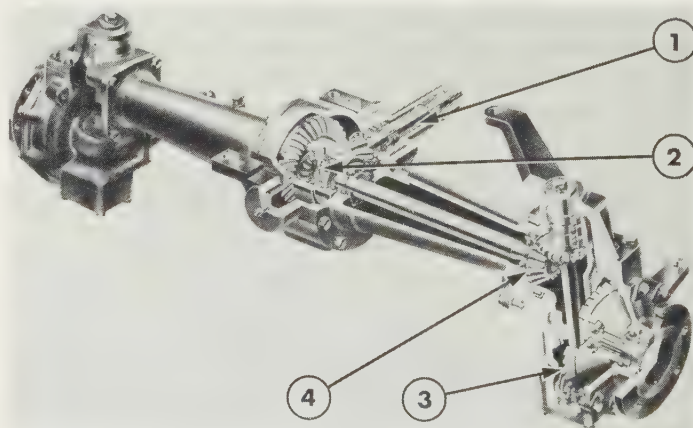


Fig. 2.45 Four-wheel-drive front axle used on 'compact' tractors. (Ford New Holland)
1 Drive shaft, 2 Differential, 3 Lower bevel gears providing reduction gearing, 4 Upper bevel gears.



Fig. 2.46 Compact tractor (16.7 DIN hp) working in a commercial glasshouse. (*Ford New-Holland*)

Some European narrow-track tractors have four-wheel-drive by equal-sized wheels, and articulated-frame steering of a type that can provide a very small turning circle. These have engines of up to 45 hp (33 kW) and are used mainly for cultivation, often with a rotary cultivator, or for spraying. This type has a low overall height to permit work beneath umbrella-shaped trees. Very specialised vineyard tractors used in some parts of Europe employ a design which allows the tractor, equipped with built-in spray tanks, to straddle the rows. Hydrostatic transmission assists in achieving a sound method of delivering power to the drive wheels.

Cabs and seats

It is only practicable here to comment briefly on safety and ergonomic aspects of tractor designs. Great progress has been made with standard test codes for components such as cabs and seats; and some standards are enforced by regulations. Standards specify, among other details, the space available for the operator, the position of basic controls, and maximum forces needed to operate them. Modern designs include shock-absorbent cab mountings;

good sound-insulation linings; provision of heating and ventilation; easy access; an uncluttered floor, and good all-round vision. The use of hydraulic and electro-hydraulic controls provides flexibility in location of cabs, as well as finger-tip operation.

The best suspended tractor seats now provide a good compromise between the soft springing and light damping that can provide a very smooth ride, and the necessity to avoid large movements that make safe operation of conventional controls impossible. The best designs ensure that the movements are approximately vertical, and that there is sufficient adjustment to allow for drivers of different weights and heights, assisted by a telescopic steering wheel with adjustable shaft angle. A few degrees of seat swivel can be useful when rear-attached machines are used. Standard rig tests for assessing practical performance are available, and being steadily improved.

Commercial suspended cabs

Advances in the development of suspended tractor cabs were promoted by several years of continuous experimental work by NIAE, now Silsoe Research Institute. The broad conclusion reached was that a good cab suspension is capable of providing the means of achieving a far better ride for the driver of a modern tractor than is obtainable by use of a good suspended seat alone. The basic reason for the improvement found possible was simple: the available amount of suspension travel was greatly increased; and the greater mass of the cab could make an effective system easier to design. Moreover, the certainty of a continued and rapid increase in adoption of electro-hydraulic control of transmissions and of tractor operated machinery in general would in any case substitute grouped finger-tip controls for mechanical levers in tractor cabs of the future. The time was therefore ripe for a progressive manufacturer with easy access to the technology of a wide range of motor vehicle suspension systems to continue the development to a commercially acceptable product.

The Renault 'Hydrostable' suspended cab, available as an option in the TZ series ranging from 81–123 kW is connected to the main tractor frame by four shock-absorbers, plus anti-surge and anti-roll bars. It incorporates a fully adjustable hydraulically suspended seat of high quality: has an adjustable steering column, and has the tractor controls linked to the movable cab by flexible

cables or hoses which are easily operated and were found in practice to cause no serious troubles.

Official test measurements of vibration and physical shocks to operators have indicated that severity compared with a conventional cab and an unsuspended seat was reduced by 66%. When a similar suspended seat was used with and without the hydrostable cab, reduction was 42%.

The transverse and lateral rods restrict sideways and fore-and-aft independent movement of the cab during work, and an anti-roll system is additionally provided by short torsion bars on both sides. Measurable results of the whole suspended cab package are claimed to be:

- (1) At the same level of operator fatigue over a long working day, a 75% increase of tractor output.
- (2) At the same forward speed and length of working day, a much reduced level of operator fatigue at the end of the day.

Reports of a sample of commercial British users visited by RASE Machinery Award Scheme judges in 1988–9 were so favourable that the entry received the RASE Gold Medal award in 1989. It is therefore likely that there could be development effort in similar directions by other manufacturers.

The interest in noise levels within closed cabs of both tractors and powerful self-propelled machines, first stimulated by compulsory operator health and safety regulations many years ago, has been taken over by design engineers, manufacturers' sales directors and by progressive users as a performance subject deserving serious consideration from drawing board to buying for practical use on farms. Manufacturers have been justifiably pleased to relate how new engine piston top designs, linked to precise timing of fuel injection, have produced remarkable improvements in torque back-up and fuel economy, and at the same time have appreciably reduced bystander noise.

In another engine series, redesign of the engine crankshafts alone achieved a reduction of OECD test levels of 4 dBA, equivalent to a 50% reduction of perceived noise in most use conditions. Other very significant improvements were made by such measures as using a 4 mm steel plate between the engine compartment and the cab, plus fitting an effective sound insulation mat on the cab floor. Other new practices found effective in noise reduction without going as far as the fully suspended cab are vi-

bration reduction by fitting rubber bearing pads to all of the cab support pillars.

Simple tractors

It is debatable to what extent less developed countries need either to make or to buy simple tractors of low power, as opposed to the trends towards high power and sophisticated design general in countries where agriculture is highly mechanised. If the need for simple tractors is accepted, there remain wide differences of opinion on essentials of specification.

In addition to technical factors, there are also problems of politics and economics which invalidate straightforward comparisons between sophisticated products produced by automated factories, on the one hand, and simple tractors made in more primitive factories on the other. Nevertheless, there are strong national arguments in favour of simple tractors partly constructed in the country of use.

Main interest centres on a type with a chassis of welded channel construction, with two large drive wheels at the rear and two small steering wheels on a centre-pivoted front axle. A single- or two-cylinder engine of 15–30 hp mounted towards the rear and hand-started leaves room for a substantial load platform between the wheels. Drive may be by V-belts and a simple gearbox, though one publicised development employs hydrostatic drive with wheel motors.

The basic problems are highlighted when operation of cultivation implements is considered. It soon becomes apparent that a Category 1 three-point linkage is a highly desirable option.

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The Motor Vehicle (Construction and Use) (Track-laying Vehicles) (Amendment) (No. 2) Regulations 1984. SI 1984 No. 1811. HMSO, London. (Refers to tracklayers.)

Tillage

Soil structure

Agricultural soils consist mainly of a heterogeneous collection of mineral particles existing either singly or as small 'crumbs' comprising several particles grouped together. Between the soil particles are spaces which may be filled by air or by water. The amount of air in a given soil and its bulk density can vary widely according to cultivations and traffic over the land. Some soils that are over-consolidated or are worked in wet conditions can easily lose their friable structure. Soils in such a condition do not provide a suitable environment for some agricultural crops, and one of the chief uses of cultivation implements is to restore a 'tilth' favourable to crop development.

Soils vary widely in their suitability for 'minimum' cultivation in its extreme form — 'direct drilling'. Favourable soils include those on gentle slopes overlying chalk or limestone, and well-drained medium loams. On these, both winter and spring cereals can be direct-drilled on a continuous long-term basis without loss of a good structure. Calcareous clays and well-drained loams over clay can be suitable for direct-drilling of autumn-sown cereals but are less reliable for spring drillings. Unsuitable soils include sands with a low organic matter content, silts, and badly-drained clays. Among crops unsuitable for direct-drilling owing to soil structure problems are practically all 'root' crops.

Control of soil moisture, temperature and aeration

Tillage is concerned in many ways with the adjustment of the soil moisture content to the needs of the crop. Heavy soils are cultivated and left rough and open at the surface in order that rain may easily penetrate and quickly pass

down into the drains. On the other hand, it may be desirable at seeding time to produce at the surface a fine crumb structure to keep any moisture deposit in the upper layers. At other times, in preparing an early seed-bed on a wetter soil, it may be necessary to produce a rough, broken surface to induce a partial drying of the surface layers. In drought areas where infrequent but very intensive storms occur, one method employed to assist percolation of heavy rainfall is to leave the surface



Fig. 3.1 Double-row front-mounted swing-over furrow press used in conjunction with well-set large skimmers on a matching reversible plough provides effective non-stop seedbed preparation in a single pass where a mat of surface trash needs to be buried. The hydraulically operated centrally pivoted front-mounted press is attached by heavy-duty brackets to both sides of the tractor frame and helps to balance the weight of the reversible plough on headland turns, and when being moved along roads. (Dowdeswell)

of the fallow land in the form of large basins, so that rain is collected instead of being allowed to run off the surface. Consolidation may sometimes have important effects on the movement of water through the capillary spaces in soils, but the effects of this have been shown to be less important than was at one time supposed.

Tillage and weathering modify the air spaces in the soil, as well as the sizes of the soil particles. Aeration, like many other results of tillage operations, is imperfectly understood. Oxygen is certainly required in the soil for the germination of seeds, the respiration of plant root systems and the activity of some beneficial bacteria. It is also certain that it is good practice to leave land in a fairly 'open' condition over winter, so that rain and air can percolate easily. In these circumstances, the soil becomes 'sweet' and 'mellow'; but it is not possible, in the present state of knowledge concerning such matters, to estimate how much of the improvement is due to aeration.

Soil temperature is closely bound up with such variables as moisture content and compactness. For example, soils which are wet in spring are cold because of the high specific heat of water compared with that of soil, the result being that the effects of a warm atmosphere are less rapidly felt on the wet soils because a great amount of heat is required to warm the water in them. Generally speaking, improvements in soil temperature conditions are brought about incidentally in the performance of tillage operations where the main objective is to modify texture and moisture content.

Destruction of weeds

Developments in the use of herbicides have been so successful and far-reaching that it is now possible to grow some arable crops without any tillage operations aimed solely or even primarily at weed control. The efficiency and speed of carrying out essential tillage work have also been substantially improved, and use of herbicides is not necessarily cheapest where cultivations are beneficial for purposes other than weed-killing. It is therefore still useful to bear in mind some basic principles of weed control by tillage which were proved before the benefits of advanced herbicides were available.

One of the chief objects of stubble cleaning is to germinate weed seeds so that they may be killed by subsequent cultivations. This technique works well with chickweed,



Fig. 3.2 The hinge-linked culti-packer roller and 'Lift-pack' design of the drill lift connections reduces by up to one third the lift force required to raise the drill to a safe position above the packer roller for headland turns and transport. (*Fendt Farmer Turbomatik with Amazone matched power harrow, crumbler and drilling equipment*)

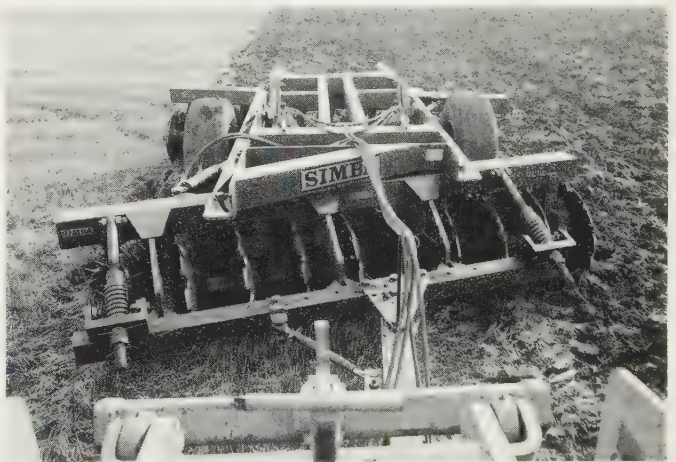


Fig. 3.3 Heavy two-gang offset disc harrow 3.8 m wide with ten large diameter discs per row spaced 400 mm apart for 200–250 mm (8–10 in) deep work on straw incorporation. The implement is seen working on heavy clay on a wet November day in a full crop of chopped and spread straw. The straw was thoroughly incorporated to a depth of 225 mm (9 in) in two passes. A press roll used at the rear in normal moisture conditions was not in use and not needed in these conditions. Quoted power required approximately 260/340 hp (see Chapter 6 for other types). (*Simba Series 4*)



Fig. 3.4 Front-weighted four-wheel-drive tractor with rear-mounted RAU Rototiller and packer-roller producing a seedbed suitable for once-over drilling from rough ploughing using S.A. COMPACTOR Accord pneumatic drill. (Ferrag)

speedwells, cleavers, black grass, poppy and charlock, to mention a few; but there are some weeds such as corn buttercup, fat hen and knot grass which often do not germinate until late in the year.

With wild oats, cultivation may help to protect the seeds from birds and rodents, with the result that absence of cultivation may sometimes lead to fewer viable seeds being left to grow in the succeeding crop.

Inter-cultivations between rows of growing crops are generally aimed at the destruction of weeds, and experiments both in this country and abroad show that keeping the soil free from weeds is the important factor, and that stirring the soil is relatively unimportant. Indeed, careful experiments have shown that with crops such as sugar beet and potatoes, etc., additional hoeings beyond the amount necessary to control weeds may reduce yields rather than increase them.

Burying rubbish and mixing of fertilisers

Crop remains and farmyard manure must be buried and mixed so that the manurial constituents contained in them may be made available to the crop plants by processes of decay, and so that their presence on the surface may not

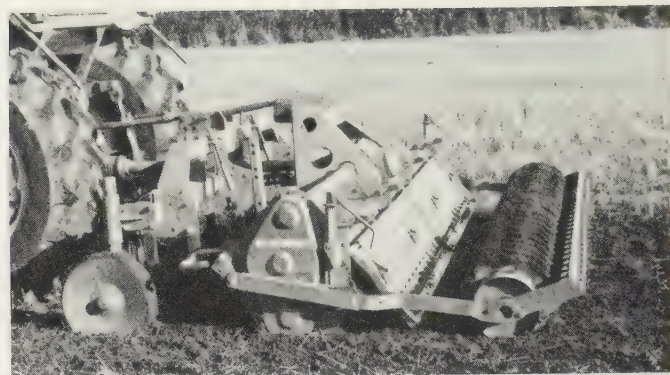


Fig. 3.5(a) Three metre combination cultivator working in long stubble.

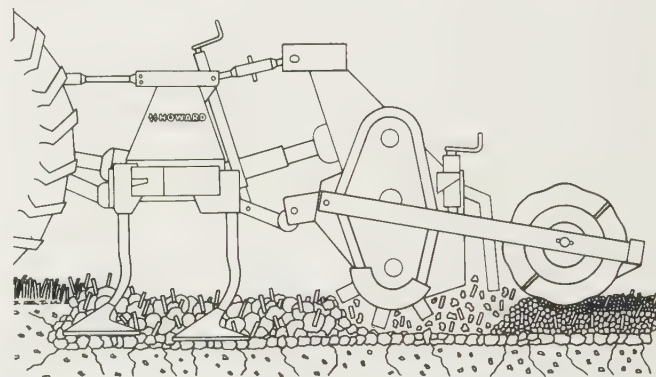


Fig. 3.5(b) Howard grubber chisels in combination with Howard Rotalabour F1 rotary cultivator and Packer Roller. The VGS Grubber chisel tines with Rotalabour F1 blades (See Chapter 6) and toothed or fluted packer roller provides an effective primary straw incorporation machine, available in width 2.5 to 4 m. The positively depth regulated tines in two rows can work at 75–200 mm (3–8 in) depth. For rotor choices see Fig. 6.18.

interfere with cultivations. The plough, with its inverting action, is widely used for this operation, and one of the chief requirements of good ploughing in British conditions is that all rubbish should be buried. The necessity of burying all rubbish does not, however, apply to ploughing throughout the world, for there are areas in the United States, the Canadian Prairie Provinces and in other countries, where serious wind erosion may occur if all rubbish is buried. In such circumstances, one of the chief requirements may be to leave as much rubbish as possible anchored but protruding from the soil surface.

Changing tillage needs in Britain

Straw incorporation

During the 1970s, increased areas devoted to autumn-sown wheat, barley and rape, wider acceptance of continuous cereal cropping, and earlier sowing of all of these crops combined to minimise the number and depth of tillage operations between combine harvesting and drilling. Properly conducted field trials showed that on favourable soils, where structure had not been much damaged by 'tramlines' or other wheelings, cereals and rape could be successfully grown with only 'minimum' cultivation, or even by 'direct drilling' without any cultivation as such. Burning of straw commonly made such practices effective by reducing trouble from blocked drill coulters, killing a proportion of weed seeds, and eliminating toxicity to germinating crops caused by acids formed in the early stages of decomposition of cereal straw. Skilful use of autumn-applied residual herbicides helped in avoiding a build-up of autumn-germinating weeds, provided that just enough cultivation was done to move the ash layer and crush any large clods before spraying.

In the 1980s an increasing number of cereal growers had become equipped with powerful tractors which enabled them to try out fast new implements for surface cultivation and also many others for deep loosening of soil and subsoil. Favourable seasons helped to raise yields to record levels; and in a short time the confidence of both scientists and farmers in the importance of good seedbeds and of loosening the lower layers of soils as needed was quickly restored. The re-establishment of the value of moderately deep tillage came just in time to prepare many farmers for the more expensive cultivations needed to ensure effective incorporation of chopped straw.

Where the whole crop of straw has to be incorporated, there are limits to the speed of straw decay even in the unusual ideal conditions of finely chopped straw mixed into a warm, moist soil, so it is essential to begin incorporation quickly. This may enforce limiting the first cultivation to a shallow depth. The choice of operations depends on soil type, depth and condition, and the equipment available. For typical British conditions it is not usually practicable to aim at incorporation of the whole of a heavy cereal straw crop at a finished cultivation depth less than about 150 mm (6 in). On some lighter soils it may be less, but on heavy ones may sometimes

need to be a little more. In considering the vast range of types of equipment available, it may be useful to study some which combine both shallow and deep working. The following short list of some types dealt with in Chapters 4–6 serves to underline the breadth and difficulty of choosing:

<i>Main feature of implement</i>	<i>Some variations</i>
Fixed tines	Spring, spring-mounted or rigid tine rows of successively increased depth. With deep-working shares designed to avoid raising clods and stones to surface. With small mouldboard type shares set to throw the soil into shallow ridges.
Discs	Heavy, plain to assist straw burial and use of tines. Heavy concave plain, cut-away, or with extensions to assist penetration in straw.
Plough bodies	With features (trash boards, high clearance legs, etc.) to assist trash burial.
Moving tines	Rotary, with chain-driven interconnected rotors designed to secure high-speed tine action on the second rotor. Reciprocating, with pto drive to eccentric weight to assist deep penetration of hard soils.
pto-driven rotary cultivators	With fixed tines to lift soil ahead of horizontal-axis rotor. With fixed tines behind rotor to loosen lower layers. With tined rotors of improved design.
Furrow presses and heavy crumbler rollers	To assist work of all types, often making once-over operation satisfactory.

The increased power generally available in four-wheel-drive tractors often makes the achievement of once-over operations by combined implements a desirable aim. Where it is possible to round off the operation by drilling, use of tramlines can ensure that no tractor wheel runs over a crop plant in the main part of the field between drilling and harvest.

Effective straw chopping is an essential preliminary to incorporation; this is dealt with in Chapter 14. With the increased desire to practise straw incorporation many farms which need to return to medium-depth cultivation can usefully consider a return to ploughing. For others a need is deep soil loosening and there are improved implements for these purposes.

It is certain that there is nothing worthwhile to be gained by regular very deep ploughing. As a general rule 200–250 mm (8–10 in) is deep enough for root crops, and 150–200 mm (6–8 in) for most other crops. Moreover, where it is practicable to cultivate effectively to quite shallow depths, e.g. 100–150 mm (4–6 in), this can be satisfactory for most crops other than roots. Securing the best results depends on the farmer's ability to choose the right implement at the right time.

The impending prohibition of stubble burning makes it appropriate here to summarise a few general points arising from results of many carefully planned and replicated

field experiments carried out in the 1980s by ADAS on the MAFF Experimental Husbandry farms, in conjunction with the Soil Science Group of Silsoe Research Institute and in co-operation with progressive equipment manufacturers. No insuperable straw incorporation problems were met, but it became accepted that heavy straw crops which are not to be baled and used elsewhere are best chopped by the combine to a length of not over about 100 mm (4 in) and spread with the chaff as uniformly as possible.

On light and medium friable soils, fast shallow soil working is recommended as soon as practicable after combining, and there is a vast array of implement types and sizes to choose from. In general, pto operation is not essential, and high forward speeds with discs, blades or teeth soil driven and free to rotate on cylinders set at an angle to the direction of travel can be effective and economic. Some newer machines with chain drive to an adjacent cylinder also fitted with teeth, achieve a high working speed in the second cylinder by choice of a suitable sprocket gear ratio. A second pass may be needed later for deepening the seed-bed and/or killing weed seeds after germination.

On heavy clay soils there is usually need for deeper work from the beginning, and here ploughing, though slower and more expensive, is often the best approach. In most conditions the use of large skimmers in conjunction with a carefully chosen furrow press is ideal. With a modern four-wheel-drive tractor and front-mounted swing-over press (Fig. 3.1), most of the straw and any other surface rubbish is well pressed down into firm contact with the lower soil layers, and the experimental results confirmed absence of drilling problems accompanied by satisfactory crop yields.

Some new types of plough designed primarily for straw incorporation are included in Chapter 5. Alternatives to ploughing on some heavy soils include combinations of fairly deep-working tines with various forms of pto-driven rotary cultivators or harrows, and these are considered in Chapter 6.

The close association of progressive machinery manufacturers with field trials organised by ADAS Mechanisation and Soil Science departments and Silsoe Research Institute has led to rapid development of use of new combinations of tillage equipment which are fully capable of incorporating the remains of straw crops effectively. Some of the chief points that are worth noting may be listed as follows:



Fig. 3.6 Trailed 4 m seedbed cultivator comprising levelling blade; first spring-tine cultivator row; large diameter toothed crumbler roller; second spring-tine cultivator row; and water ballasted rubber tyred crumbler roller, with rear-mounted Accord DA pneumatic seed drill. The DA is designed for combination mounting on a cultivation implement, often a power harrow. The cultivator model illustrated is operated by a tractor fitted with very wide Terra-tyres, with outside wheel track equal to the width of the cultivator. The combination is moved between fields with the front raised and the implement running on the rubber rear crumbler roller. Wider models can fold wings longitudinally or be end-towed depending on customer preference. (*Simba 'Top-Tilth' with ACCORD DA drill*)

The basic objectives for rapid straw breakdown are an early start, short chop and even spread, followed by a good mix with moist soil and use of press rolls of various types to prevent unnecessary moisture loss and begin preparation of a top tilth. Since an aim is often autumn sowing, and a reasonably good tilth for even germination of seed is desirable, a second operation to kill germinated weeds, and to secure a deeper tilth to encourage root development may be desirable: and if the subsoil needs loosening to encourage deep rooting, a combination which includes use of subsoil tines may be worthwhile during the second operation. A small booklet outlining the range of systems offered by one specialist tillage equipment manufacturer, based on full co-operation with ADAS and experience with the straw incorporation experiments, makes instructive reading.

Some of the newer developments are reviewed in Chapters 6 and 7, and it is relevant here to note the rapid increase in use of the many combinations of equipment for cultivating and sowing in one operation. Most of these are based on compact pto-driven power harrows or rotary cultivators combined with an effective toothed packer roll and mounted drill. Pneumatic drills can be particularly well suited to once-over work on account of lightness of the machine and ease of folding the coulters for transport. The Simba Top Tilth trailed seedbed cultivator/drill designed as a low-cost alternative to the power harrow/drill systems (Fig. 3.6) is an example of another system of simple design capable of high outputs due to high forward speed, with consequent fuel economy, and claimed low cost of wearing parts.

Mechanisation and soil structure

Adequate tractor power and suitable implements make it possible to undertake operations that would be out of the question without them. For example, so much advantage can be taken of short favourable periods in autumn or spring that a cleaning effect comparable with that of a half fallow may often be obtained in less than a month; heavy land can be burst up when it is dry, and need seldom be worked when too wet, with the result that soil structure becomes greatly improved; spring cultivation may be done so rapidly that moisture losses are negligible; and seedbeds may be made just as fine or firm as necessary, with a minimum expenditure of time and trouble.



Fig. 3.7 12 m Gantry with three 4 m units of rows of spring-tined cultivator. (Dowler Gantry Systems)

High-powered tractors need a considerable amount of weight to be carried by the wheels or tracks in order to make full use of their draught power; and when soils are wet tractor wheels can cause puddling of the soil, either by sheer compression or by smearing. These bad effects are particularly marked in wet, late seasons, when crops have to be carted off waterlogged land. The aim of mechanisation must be to equip in such a way that work does not have to be carried out in the worst soil conditions. This is, of course, a counsel of perfection which cannot always be followed.



Fig. 3.8 12 m Gantry with sprayer. Two boom extensions make total boom width 24 m (79 ft). (Dowler Gantry Systems)



Fig. 3.9 Dowler Gantry prototype trying out pneumatic drill. (Dowler Gantry Systems)

The Dowler Field Gantry Bed System

The first signs of commercial success in the use of gantries for crop production were in vegetable crops both inside wide-span glasshouses and in areas of intensive production outdoors, where selective harvesting of tender crops in first class condition is an objective.

In general farming applications, bed systems for potatoes and sugar beet have hitherto tended to be linked to use of conventional multi-purpose tractors, but the prospects of commercial use of gantries in general agricultural cropping systems need now to be reviewed in the light of the development work carried out during the 1980s by David Dowler, a Warwickshire farmer with 93 ha (230 acres) of general cropping on fairly heavy land. His pioneering work has resulted in a soundly based 12 m (40 ft) span gantry which appears surprisingly attractive to farmers interested in avoiding the adverse effects of running over well tilled heavy land when it is just too wet to support the weight of conventional agricultural tractors and their equipment without excessive compaction.

Mr Dowler's fields range in size from 3.2 to 14.5 ha (8–36 acres): all are the same size and shape as they were before the gantry was developed. Checks by Silsoe Research Institute whose work on gantry developments has also continued over several years have confirmed by scientific measurements of equipment draughts and outputs that keeping the power unit off the cropped land showed energy use comparisons of only 79 MJ/ha on gantry system sites compared with 253 MJ/ha for a conventional system involving tractor ploughing. In practice, cultivation by gantry has resulted in appreciable fuel savings.

The present gantry production machines are so manoeuvrable that there is no intention either to alter gantry design or to change the shape or size of any of Mr Dowler's fields.

Powered by a 90 hp Perkins diesel engine and driven by hydrostatic wheel motors located in the large wheel located at each end of the boom, the Dowler gantry is very easily manoeuvrable. On field work the large drive wheels and their castors are at right angles to the length of the beam, and the full 12 m width is usable for equipment supports. For headland turns, the drive wheels driven in opposite directions produce, if needed, a pivot turn based on the centre of the beam, either before or after moving lengthwise as on the road transport mode.

The seat and controls in the cab pivot through 270° to accommodate moves forward, backward or sideways. A spray tank is accommodated at the end distant from the cab. Most-used equipment has been: 3 × 4 m spring-tine cultivator/harrows, 3 × 4 m pneumatic drills, and sprayer with boom width up to 24 m (79 ft) with extension booms.

References

- Marshall, Ian (August 1990) 'Straw Incorporation' *Power Farming*, 90(8), 25–7.
- Straw Incorporation Systems*, Part I, compiled by SIMBA Machinery in association with ADAS.

Ploughs: Components and Operation

The essential feature of ploughing by mouldboard plough is that a layer of soil is separated from the underlying subsoil and is inverted, so that any vegetation or manure present on the surface is buried, and a layer of soil from below is brought to the surface, where it is exposed to the action of weathering agents and of other implements. The ploughed land is laid up in furrow slices, the type of slice depending upon the type of plough used and the nature of the soil. Ploughing is often the most important operation of the arable farmer, not only because of the basic nature of the work but also from the standpoint of the power required.

Plough components

The terms commonly used to denote the principal plough components are varied, but an attempt has been made to remove ambiguity by the establishment of a British Standard Glossary of Terms, BS 2468:1963, which gives a list of agreed terms and definitions for most of the common agricultural implements and machines, together with their principal parts.

The term *body* refers to the complete assembly of working components for a single furrow. The terms used for types of body by different manufacturers vary considerably:

- 'General-purpose' usually implies a body suitable for unbroken shallow work (up to about 200 mm deep).
- 'Semi-digger' implies suitability for partly broken medium-depth work (up to about 250 mm deep).
- 'Digger' indicates ability to produce broken work at a depth up to about 300 mm.

These basic terms are often supplemented by 'high-speed',

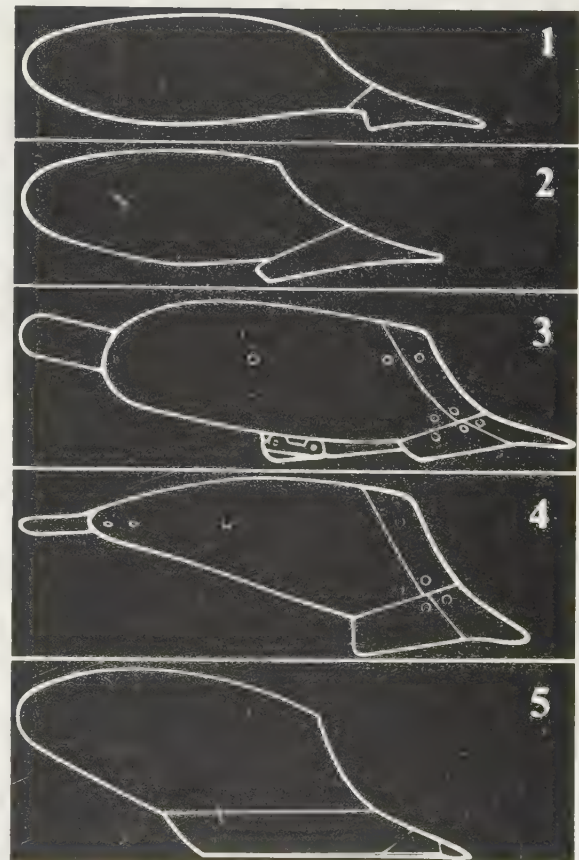


Fig. 4.1 Typical plough body shapes

1 General-purpose, 2 Semi-digger, 3 General-purpose 'high-speed' type, 4 Semi-digger 'high-speed' type, 5 Deep digger.

which may imply low draught or small, easily renewed wearing parts, or special facilities for shock protection, such as a safety break-away mechanism.

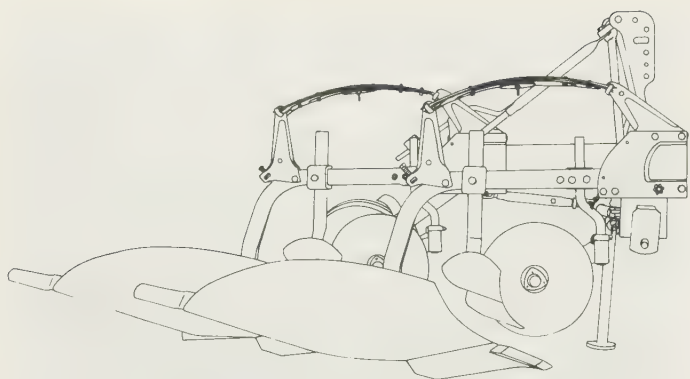


Fig. 4.2 Plough with simple spring-mounted auto-reset bodies incorporating reinforced chisel share points. (Kverneland UK)

Modern ploughs tend to have a single tubular main frame member running diagonally, with very simple arrangements for removing or adding complete bodies and so changing the size of plough to suit the job or the power available. Changes of angle of the main beam and of the individual bodies provide for quick changes of furrow width.

For use where immovable obstructions such as bog oaks or rock outcrops are likely to be encountered, a spring-loaded leg which can trip at a given overload is provided by many manufacturers. When the trip is operated, the trip beam usually rotates about a pivot attached to the main beam, and raises the body out of work (Figs 4.5; 4.7).



Fig. 4.3 Reversible ploughs with slatted mouldboards and reinforced chisel share points are widely used on light flinty soils in many European countries. (Krone)



Fig. 4.4 Plough components (Ransomes) A Main frame, B Leg, C Semi-digger body, D Landside and slade, E Disc coulters with tilt adjustment, F Skimmer, G Cross-shaft and hitch pins, H Width control by rotation of cross-shaft.

The *share*, which makes the horizontal cut separating the furrow slice from the soil below, fits on to the front of the frame. Ploughshares, like mouldboards, are of very varied shapes. The share of the lea plough has a definite 'neck' that has the effect of placing the cutting edge well in advance of the mouldboard. This 'lead' at the cutting edge assists in keeping the furrow slice unbroken, allowing it to rise gently up the mouldboard without any pulverising action. The cutting edge of the digging ploughshare is close to the forward part of the mouldboard and often almost at right angles to the line of draught. Points and wings are usually separately renewable.

Shares of medium-depth ploughs may be made of chilled cast iron. Cast alloy and forged steel are used for deep work. Chilling of the underside and landside of a cast iron share makes these parts wear more slowly than the upper part and renders the share self-sharpening. When chilled cast iron shares become blunt they may be improved by grinding the upper edge. When a steel share becomes blunt, it may be sharpened by a competent smith by



Fig. 4.5 Method of plough construction with single diagonal beam and parallel action furrow width adjustment allowing easy change of furrow width on the go. Bodies fitted with trashboards above and ahead of mouldboards help to bury stubble completely. (Kverneland)

beating out and rehardening. Steel shares may be cast in one piece or made of two or three pieces of metal welded together. Whether the share be of crucible steel or soft-centre steel, the method of sharpening is the same. The edge of the share is heated in a forge to a cherry-red colour, and the upper side is hammered out, the lower side being laid flat on the anvil. Only a small piece should be heated at a time, work being started at the point and finished at the wing. Care must be taken to avoid spoiling the 'suction'.

Steel shares can be treated to give very long wear by using a welding outfit to apply a layer of stellite, or other very hard compound, along the bottom side of the cutting edge.

On rocky or hard, stony land, the 'bar point' share may be used. This consists of a steel bar which passes through the frame and forms the point of the share. When the point has become blunt, the bar may be turned over or reversed end for end. Under extreme conditions,

use of the bar point share results in considerable economy owing to its comparatively long life.

The *mouldboard* is the part that inverts the furrow slice in the case of the general-purpose plough and pulverises it in the digging type. It is bolted to the frog, the countersunk bolt heads fitting flush with the face. The general-purpose mouldboard is long, and turns the furrow slice slowly, firmly pressing it into place against the previous one. It is convex from top to bottom throughout its length. In the digging body, the action of the mouldboard is very different, for the furrow slice is shattered by the use of a short mouldboard which is concave both from top to bottom and from shin to tail. The furrow slice rises rapidly up the mouldboard and is bent back upon itself and finally thrown aside by the abrupt curvature. The vertical cut is often made by a special renewable 'shin' or 'cutter' attached to the mouldboard, but where a coulter is used, it is placed nearer to the mouldboard than with the general-purpose plough.

Simple types of *slatted mouldboard* have been found in tests by the University of Hohenheim to be appreciably lower in specific ploughing resistance than comparable mouldboards of conventional types. Differences of 15–20% were fairly constant at all ploughing speeds within the test range up to 10 km/h. Owing to the increased resistance of all types of bodies at higher speeds, the upper end of the range is of particular interest in respect of rapid incorporation of chopped straw on light soils. Short, slatted digger-type bodies used at high speed, with simultaneous use of a furrow press, can often provide a finish ready for drilling in one pre-drilling operation. Slatted bodies also offer benefits on some soils very high in organic matter where failure to scour is a problem. More generally, with good design, choice of steels and hardening treatment, the cost of replacement parts can be lower on abrasive soils. It seems likely that slatted types of body will increasingly need to be included in the range of leading plough manufacturers.

The *landside* is the part that receives the side thrust due to the turning of the furrow slice. It is bolted to the side of the frame opposite the mouldboard and is usually made of hard cast iron. The 'slade' or 'heel' receives the downward pressure due to the weight of the plough and of the furrow slice. It is bolted to the bottom of the frog and is often part of one L-shaped casting which performs the dual purpose of landside and slade. Practical trials of ploughs comprising matched right- and left-hand bodies working side by side without any landsides indicate that on some soils and types of work there may be appreciable savings in draught and implement costs from elimination of this component, provided that a compensatory soil levelling process is not too expensive or troublesome.

The *coulter* makes the vertical cut separating the furrow slice from the unploughed land. The knife coulter is fastened to the beam by a clamp, which permits adjustments to suit the work. The coulter acts as a knife, and the sharper it is, the better; but it must, of course, be thick enough to withstand wear and shocks.

The *disc coulter* is used where the knife type would cause difficulty by blocking, i.e. on most tractor ploughs. The disc coulter has a tendency to act as a wheel and lift the plough out of the ground, and can therefore only be used, in hard ground, on such ploughs as are adapted by their weight and design to counteract this tendency. The disc type is almost universally used on tractor ploughs, except in very hard ground. Wavy-edge discs may be

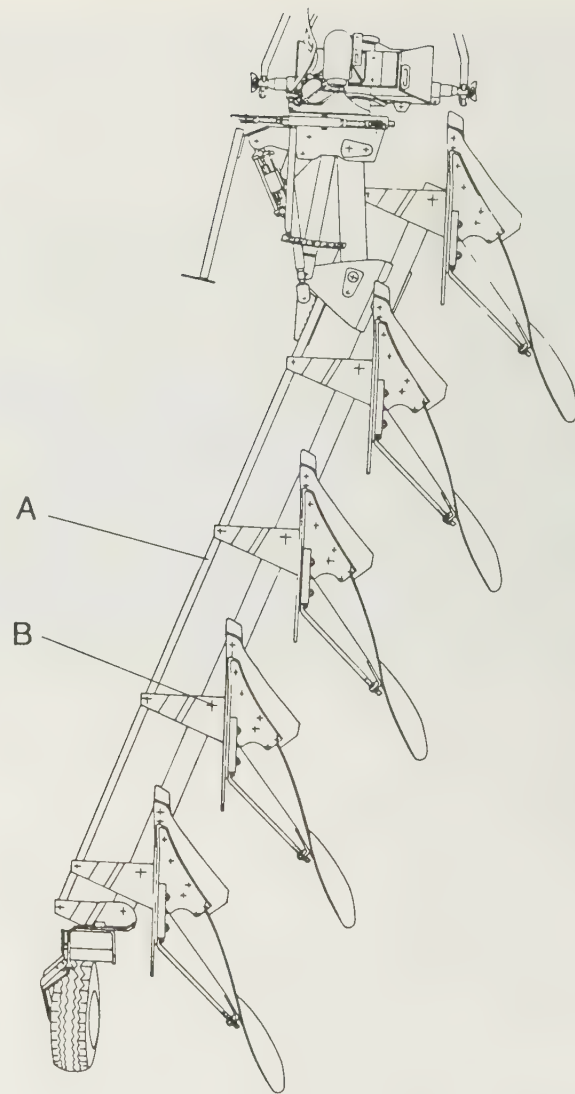


Fig. 4.6 Adjustment of furrow width by hydraulic-powered change of angle of main beam. Each leg assembly is mounted on the main box section by large pivot bolt B; the angle of each body to the main beam is varied by actuating rod A. Furrow width can be changed on the move from 30–50 cm (12–20 in). (Kverneland)

used with advantage where straw or other loose rubbish pushes along in front of plain discs. Knife coulters are often used on animal-draft ploughs in developing countries.



Fig. 4.7 Effective turf burial by well set skim coulters is well illustrated on 4-furrow reversible plough with auto-reset bodies. (Dowdeswell)

The *skim* coulters are used to assist in the complete burial of manure, rubbish and crop remains. It may also be used where land is to be worked down to a seedbed immediately after ploughing, to cut away the corners of the furrow slices in order to facilitate the production of a firm bottom to the seedbed. The skimmer consists of a miniature plough, fixed rigidly to the beam in front of the knife or just behind the disc.

Trashboards are used for purposes similar to those of large skim coulters and are particularly designed for burying loose straw. One type which is fitted to each plough body (e.g. Dowdeswell) consists of two components,

having an extended shin which is fitted to replace the conventional one with the trashboard mounted on top of it. The trashboard can be mounted in one of two positions according to working depth need; its angle is adjustable. It leaves the leading edge of the plough body clear. In work it pushes the trash from the top of the furrow and distributes it across the profile of the previous one, leaving clean soil to be raised and turned by the mouldboard, so burying the trash.

The main constructional features of common types of tractor ploughs and various special ploughs are described in Chapter 6.

Setting and operation of ploughs

Correct setting of the plough leads to fuel economy and a better standard of work. It is, moreover, essential to do good ploughing in preparation for seedbeds, since uniform work will save much time and trouble, especially when ploughing old grassland or leys. The chief adjustments needing attention are the pitch of shares and bodies, the set of the coulter, the width of furrow and the hitch between plough and tractor. These adjustments are dealt with in turn below. When a plough is properly set, it should run steadily along, cutting a clean surface on the furrow wall and bottom. The plough body should run level, the heel of the landside just rubbing against the furrow wall, the heel of the slade sliding smoothly over the furrow bottom, and the share running level.

The share

Correct setting of the share is essential. If a straight-edge be laid from the point of the share to the heel of the landside, there should be a gap of about 3–9 mm ($\frac{1}{8}$ – $\frac{3}{8}$ in) between the straight-edge and the share at the point where the share and the landside meet. This is called the 'land' or 'land suction' of the share. Similarly, the point of the share must be inclined downwards about 3–12 mm, ($\frac{1}{8}$ – $\frac{1}{2}$ in) and this setting is called the 'pitch'. Both pitch and land requirements vary widely according to the type and condition of the soil. The softer the soil, the less pitch and land are required to keep the plough running smoothly and cutting its full depth and width.

Faults in the construction, fitting or setting of the share cannot be remedied by adjustments elsewhere. If the share has insufficient suck, for example, it may be possible to keep the plough at work by shortening the top link; but if this is done, the plough will run on its nose, with the heel of the slade off the furrow bottom. In such circumstances the implement is difficult to handle, and bad work is done, the share gouging the furrow bottom and leaving the depth of work irregular. In a similar way, adjustments of the hitch in a horizontal direction will not remedy incorrect setting of the 'land', which may cause the plough to run towards or away from the unploughed land.

On most modern tractor ploughs, the pitch of the complete body in relation to the beam may be varied

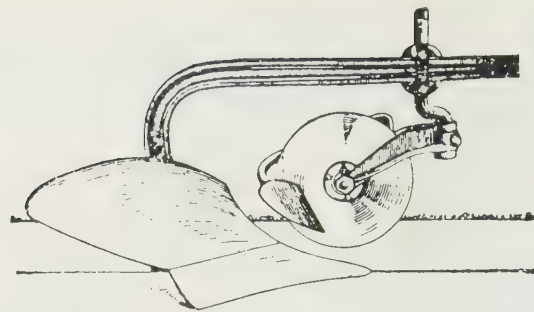


Fig. 4.8 Combined skim and disc coulters.

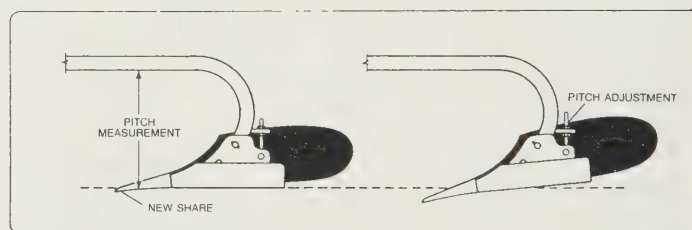


Fig. 4.9 Pitch adjustment.
Left: body with correct pitch.
Right: too much pitch.

easily, e.g. by the use of the set screws and a slotted frame, or by an eccentric device in the frame.

The 'pitch measurement' is usually reckoned to be the vertical distance from the underside of the share to the bottom of the beam, and when making adjustments to get all the bodies level, or checking a plough for strained beams, it is important to make the measurement at the correct point on the share (Fig. 4.9). Some manufacturers advise fitting new shares and measuring from the share point. The pitch adjustment cannot be employed to correct for beams which have been severely distorted, and if, when all plough bodies are given the same pitch adjustment, one share point is found to be much lower than the others, it is usually an indication that the beam needs to be removed and reset, or replaced.

The coulters

The coulters, whether it be of the knife, disc or skim type, must be set correctly for the performance of good work.

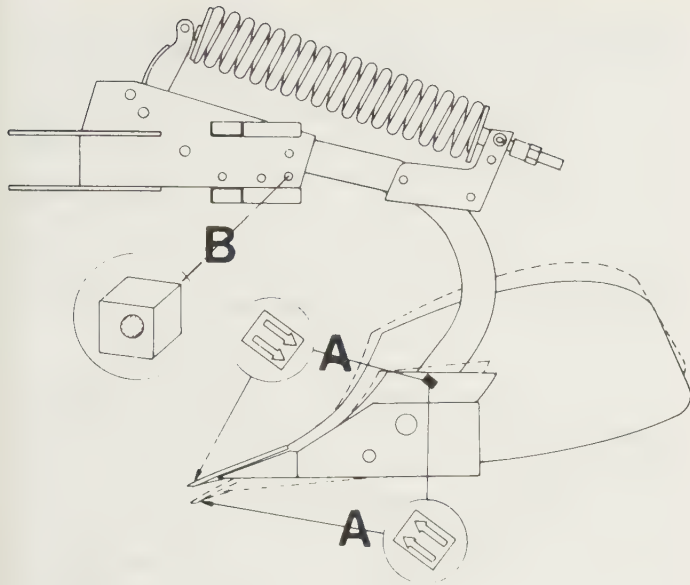


Fig. 4.10 Two-position pitch adjustment
Rough adjustment is made by reversing eccentric bolt A.
Dotted lines indicate alternative body position. Fine adjustment is effective at beam fixing point, B.

The knife coulters is usually set with its point slightly forward, so that it forms an angle of from 55° to 85° with the slade; but where stumps or rocks are encountered, the angle may be increased to over 90° so that the plough is thrown out of the ground if the coulters strikes an obstruction. For normal work, the point of a knife coulters is set 12–25 mm ($\frac{1}{2}$ –1 in) above the point of the share and 12 mm ($\frac{1}{2}$ in) towards the unploughed land. The coulters, like all other cutting tools, must be given a clearance behind the cutting edge, so that the side which is towards the unploughed land does not rub hard against the furrow wall. The clearance at the back edge should be from 1.5–3 mm ($\frac{1}{16}$ to $\frac{1}{8}$ in).

For average conditions the disc coulters should be set 10–20 mm ($\frac{3}{8}$ – $\frac{3}{4}$ in) to the 'land' side of the share point, and a vertical line dropped from the axle of the coulters should fall just behind the point.

Bad coulters-setting is responsible for much bad tractor-ploughing. Discs always tend to run narrow, and it is easy to show with the help of a dynamometer that setting

the rear disc too narrow causes a considerable increase of draught (often 200–300 lbf (0.9–1.3 kN) with a three-furrow plough) as well as bad work.

In hard going it is necessary to draw the disc back so as to give the share a 'lead', to set the disc shallow and to check the setting to land every few hours.

For ploughing old turf the disc should be set well forward, to allow the turf to be cut and the skimmer to operate before the furrow slice is lifted by the share. In normal conditions the bottom of the disc may be set about 25 mm (1 in) to 50 mm (2 in) above the top of the share, while in very matted turf it may go deeper.

Modern disc coulters have a fitting that allows them to be tilted. With the discs set over 2–3 notches, so that the lower edge undercuts the unploughed land, a crested furrow slice is produced; and this often gives a good result with rough old turf where skimmers will not function effectively.

The skimmer

Skimmers are of two main types: a large one with a straight shank attached direct to the plough beam, and a smaller combined skim and disc coulters. Both types should be set with the point close to the disc to avoid blocking. In difficult conditions the independent skimmer often works best.

The small skimmer is generally used to remove a small 'neck' of soil from the left edge of the top side of the furrow slice, so that weeds are prevented from continuing to grow through the cracks between adjacent slices. The large type may be set to remove the whole of the top of the slice.

Small skimmers should be set forward so that the cut is made before the furrow begins to rise. In general the cut should not be more than 25 mm (1 in) deep and 25–76 mm (1–3 in) wide and the piece cut should drop into the bottom of the furrow so that it does not prevent the furrow slices packing together.

One of the advantages of some new designs such as that of the 'Diamond' plough is that they allow efficient use of very large skimmers.

With single-furrow deep-digging ploughs a rear-attached skimmer has some advantages. It has plenty of room to work without blocking, and the skimmed piece can be made bigger. The skimmed part is pressed into the bottom of the furrow by the tractor wheel on its next round, and

the tractor runs more level because the furrow is partly filled.

The mouldboard

In difficult conditions the furrow slices may fail to turn over. If an attempt is made to press them together by setting out the tail of the mouldboard, this usually only makes matters worse, and often results in a considerable increase in draught. If the mouldboard is at fault the trouble is more likely to be cured by drawing it in; but when furrows will not turn a common reason is that the depth is too great in relation to the width.

When tractor ploughing was first introduced there was a fairly widespread prejudice against wide furrow slices; but experience of ploughing turf soon showed that it is necessary to have the width $1\frac{1}{2}$ times as great as the depth in order to do satisfactory work.

Furrow shapes – ‘diamond’ plough

A type of reversible plough called the ‘Diamond’ plough incorporates features which distinguish it from ploughs that cut substantially rectangular furrows. This plough does not use coulter of the conventional type, but makes an inclined cut with a shin on the front of the mouldboard. Clearance between the bodies of the deep digger plough is only 550 mm (21.7 in), but because there are no coulters,

saddles or landside to obstruct furrow-turning, the plough can handle trash effectively. The short overall length is a great advantage in reducing the lift force and moment. Large skimmers are fitted direct to the beam to work beside the mouldboards. The furrow left is wide and well shaped to receive a wide tractor tyre without compression of the turned furrow.

Principles of hitching trailed ploughs

With the plough body and coulter correctly fitted and set, it is necessary to adjust the hitch and the wheels to produce the required depth and width of work.

When the depth of a trailed plough is to be altered the correct sequence of operations is as follows:

- (1) Set the depth control to its new position. This will raise or lower both sides of the plough equally.
- (2) Set the levelling control to tilt the plough so that the front furrow matches up with the previous work.
- (3) On the next bout, readjust the levelling control to bring the plough back to level at the new working depth.

A complete understanding of the hitching problems of ploughs can only be obtained if the principles are understood. All the forces acting upon a plough at work may be considered as balanced about a theoretical point situated between the mouldboard and the landside, called the ‘centre of resistance’. With a plough body of ordinary proportions this point is generally about 300 mm (1 ft) back from the point of the share, 50 mm (2 in) in from the edge of the landside and 50 mm (2 in) up from the bottom of the slade. If a single chain could be attached at this point, the plough could be pulled straight ahead at a uniform depth and width. The centre of resistance of a two-furrow plough is midway between the centres of each furrow considered separately, and that of a three-furrow implement is at the centre of resistance of the middle furrow. The position of the centre of resistance may thus be roughly calculated for any plough, but it should be observed that this position is not rigidly fixed. In hard ploughing, where more pressure may be thrown on the mouldboard, the centre may move over from the land-side until it is near the middle of the plough body.

The ‘line of draught’ is an imaginary line running from

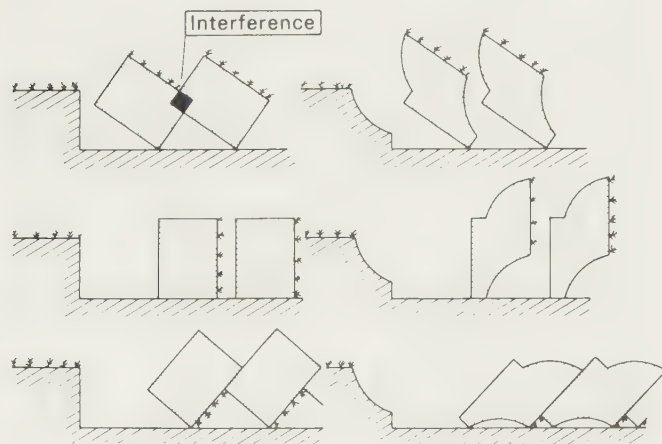


Fig. 4.11 Furrow shapes: comparison of rectangular and ‘diamond’ shapes (right).

where flexibility starts at the power end of the hitch to where it ends in the solid attachment of the implement to the centre of resistance. The best hitch is obtained when the line of draught passes through both the 'centre of power' and the centre of resistance. The centre of power for an ordinary tractor with rear driving wheels and on level ground is near a point midway between the rear wheels and slightly ahead of their centres, while with four-wheel drive and tracklaying tractors it lies further forward.

Vertical adjustments

If the point of hitch does not lie on a line joining the centre of resistance and centre of power it will tend to move into that line. For example, if the hitch at the hake is too low, the front of the plough will be pulled up out of its work (Fig. 4.12). In a tractor outfit too much pressure is exerted on the plough wheels if the hitch at the hake is too high, and this causes bad work and excessive wear of the wheel bearings. If the rear landside or rear wheel presses hard on the bottom of the furrow the hitch should be raised at the hake plates; and if the landside runs well clear of the furrow bottom, the hitch should be lowered. In general, the hitch from plough to tractor should slope slightly upwards. The vertical hitch adjustment is, of course, always influenced by the length of the hitch as well as by the hake setting.

Horizontal adjustments

The horizontal adjustment of the hitch of tractor ploughs frequently presents some difficulty to farmers. Where possible the centre of power, the line of draught and the centre of resistance should be in a line parallel to the

direction of travel, but in some circumstances, and especially when deep-ploughing with a tracklaying tractor which does not run in the furrow, this is impossible, and it is necessary to make the best hitch possible under the circumstances. The centre of resistance of the plough lies much nearer the ploughed land than the line drawn through the centre of power parallel to the direction of travel. This arrangement inevitably leads to what is called 'side-draught', a term which refers to the tendency of the two centres, when the plough is at work, to move sideways and come into line. Power consumed in overcoming side-draught is wasted, and the centre of resistance should be placed as directly behind the centre of power as possible.

When it is impossible to eliminate side-draught completely, the hitch must be made so as to distribute it between the tractor and the plough according to the amount that each can withstand. If the hitch is offset on the rear of the tractor until it is in the ideal position for the plough, the tractor takes all the side-draught; but unless it is heavy and the draught of the plough light, the front of the tractor will swing over towards the ploughed land, making it difficult to steer the outfit. With a hitch that is ideal for the tractor, on the other hand, all the side-thrust is thrown on the plough, which tends to swing round into line behind the centre of power, making good work impossible. The practical position lies between these two extremes.

Setting of tractor-mounted ploughs

While the principles of setting tractor-mounted ploughs are much the same as those applicable to trailed models, there are important differences in the methods employed for altering the depth and width of furrows and for leveling. Almost all British mounted ploughs are attached to the tractor by the three-link system, but ploughs so mounted may be divided into two major groups: those in which depth of work is controlled by a land wheel, and those in which it is regulated through the tractor's hydraulic control system.

Depth of work

The depth-regulating wheel on a mounted plough works in the same manner as on a trailed plough. On ploughs operated by tractors with automatic depth control, the

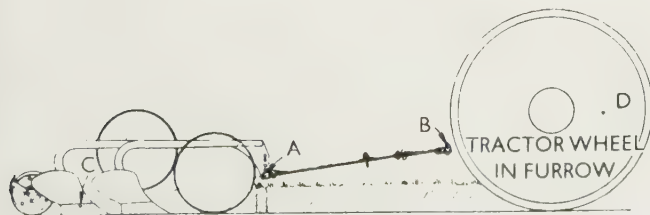


Fig. 4.12 Correct vertical hitch for trailed plough. A hitch at the hake plates, B Tractor drawbar, C Centre of resistance, D Centre of power.

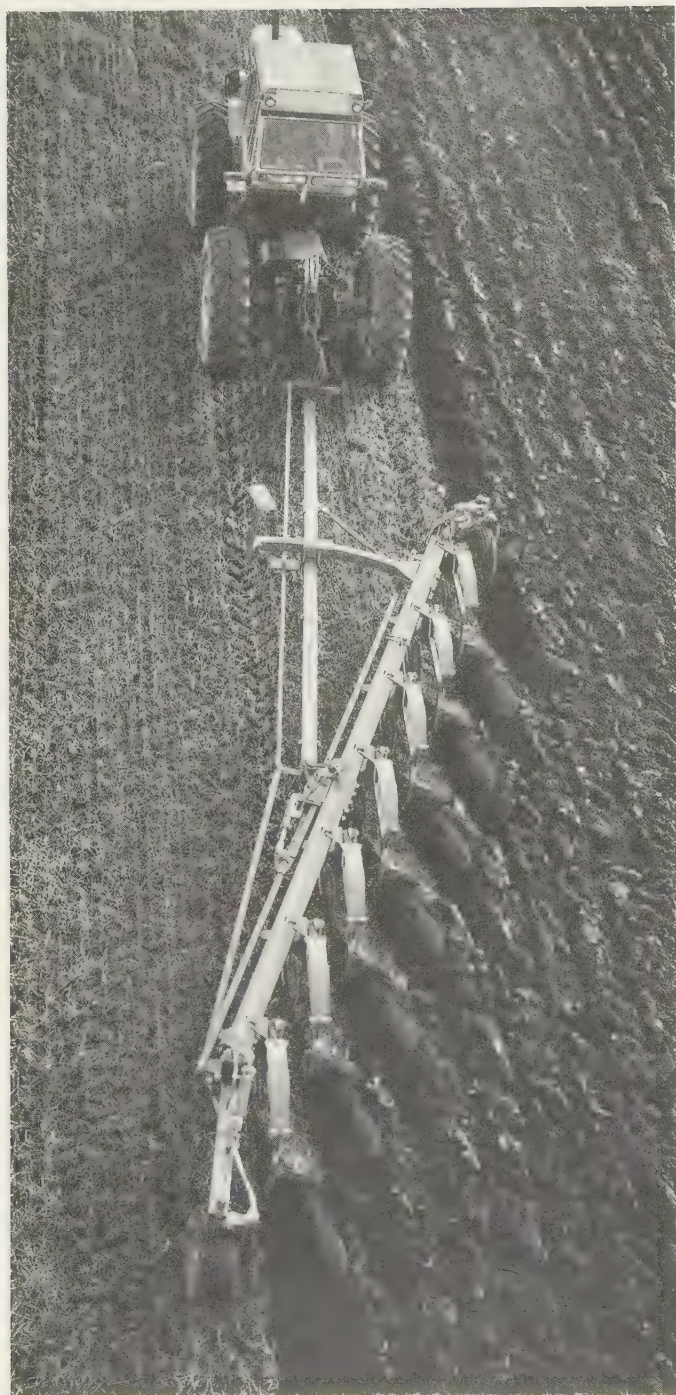


Fig. 4.13 High-powered articulated-chassis tractor runs on unploughed land using semi-mounted plough with hydraulic lift and variable width control. (Kverneland)

depth of work pre-selected by setting the hand control lever is varied or maintained by the forces acting through the linkage in conjunction with the hydraulic control mechanism. At a given setting, if the plough tends to go too deep, the additional draught increases the force in the top link and this causes the control valve to move and so raise the plough until the draught is restored to the original setting, as explained in Chapter 2.

On many tractors, the three-link system can be attached to the tractor at two different points, according to the type and size of the tractor wheel equipment. It is important that the linkage be attached to the correct points, as alteration of the height of the hitch-points above the ground has a considerable effect on plough penetration.

The pitch of the complete plough may be increased by shortening the top link, and this adjustment has the same kind of effect as raising the hitch at the hake of a trailed plough. If a mounted plough will not penetrate, it is often because it needs new shares. In general, the implement should be used with a minimum of pitch according to ground conditions; and in cases of failure to penetrate, a check should be made of the pitch of individual bodies, before shortening the top link.

Furrow width

The furrow width of a single-furrow mounted plough, or the width of the first furrow of a multi-furrow one, may be varied by adjusting the setting of the tractor wheels, and also by adjustment of the plough cross-shaft. The importance of correct tractor wheel setting should not be overlooked. It is a mistake to try to remedy incorrect tractor wheel setting by adjustment of the cross-shaft, the correct function of which is to vary furrow width *after* the tractor wheels are properly set.

The cross-shaft

Most tractor ploughs employing the three-link system are attached to the ends of the lower links by pins which form the ends of a cranked cross-shaft. Rotation of the cross-shaft alters the position of the pins relative to the plough frame. When the plough is hitched to the tractor, the pins are fixed, and the first effect of rotating the cross-shaft is to alter the angle of the plough relative to the direction of travel. When this has been done, and the plough again moves forward, the linkage and the plough

move over to the right or left relative to the tractor, until the correct line of draught is substantially restored. On most ploughs this adjustment is made by means of a screw gear, but remote control by hydraulic ram is increasingly favoured. A small angular movement of the cross-shaft will result in a substantial sideways movement of the plough.

The levelling of mounted ploughs is adjusted by lengthening or shortening one or both of the lift-arms in the three-link system, this being achieved by means of a screw gear or by a hydraulically adjustable link (Fig. 2.33).

Reversible ploughs

The principles of setting reversible ploughs are, of course, exactly similar to those for right-hand ploughs and call for little special mention. With a well-designed plough, hitch adjustments made for right-hand work should not need alteration when the left-hand body is at work; but it is absolutely essential that tractor wheel settings should be correct for the plough and the work being done, otherwise satisfactory setting is almost impossible. Tractor rear-wheel tyre pressures must be uniform, as must those of pneumatic-tyred depth wheels on the plough.

Setting tractor-mounted disc ploughs

The setting of tractor-mounted disc ploughs equipped with a depth-regulating wheel and a rear wheel follows standard mounted mouldboard plough practice except as regards setting of the rear wheel. The rear wheel setting is vitally important on any disc plough, and on a mounted disc plough it must be adjusted in conjunction with the cross-shaft setting. The inclined rear wheel normally has two adjustments: (a) lateral and (b) angular. The lateral adjustment must be suited to the furrow width cut, and will vary with soil conditions. The angular adjustment is used to steer the plough towards or away from the ploughed land, and must be used in conjunction with the cross-shaft adjustment. The angle is correctly set when fine adjustment of the cross-shaft easily alters front furrow width. Adjustment of the cross-shaft should allow front furrow width to be kept correct when working across slopes without further alteration of the rear wheel setting.

When opening lands with a disc plough the 'top' should be split, and the double-split system is usually preferable, as this leaves a level field with all the land ploughed.

Draught of ploughs

The draught varies according to the construction of the implement and the type and condition of the soil ploughed. With ploughs of good design and construction the resistance of the soil per unit area of furrow section varies from about 5 psi (34.5 kN/m²) on light, loose, sandy land to about 16 psi (110.5 kN/m²) on hard, heavy clays. Thus, a light tractor which can easily pull three furrows on a light soil may be unable to pull two furrows at the same speed on a heavy soil. It is often an advantage to have ploughs which are easily convertible both as regards number of bodies and width of work of the individual bodies; for while it is wasteful of tractor power and the driver's time to work a width appreciably less than the tractor can handle at a suitable forward speed, it is worse to try to work at a width that is beyond the tractor's drawbar pull capacity in the conditions prevailing. Ability to vary plough width 'on the go' can improve efficiency on slopes.

Methods of tractor ploughing

A normal right-handed plough cannot work to and fro, but must always work a field either in strips called 'lands', or round and round. Ploughing in lands has hitherto been the common method for tractor ploughs, just as it was for horse ploughs. With modern equipment, however, there is much to be said for round-and-round or 'square' ploughing systems.

Ploughing in lands

When ploughing in lands, the headlands must be about 7.3 m (8 yd) wide for an outfit of medium size. This width just allows the tractor to turn in a semicircle, but not to split or gather work which is less than about 7.3 m (8 yd) wide without doing figures of eight. It is, therefore, necessary to work on two ridges, as shown in Fig. 4.14. With ridges set up at A,B,C, etc., zones 1 are first ploughed by working on ridges A and B as illustrated. When at least 7.3 m (8 yd) has been ploughed in this manner on ridge A, zones 2 are ploughed by gathering the work around A. The work is then quite straightforward, zones 3, 4, 5, etc., being ploughed out successively in the manner illustrated. There is less idle running with

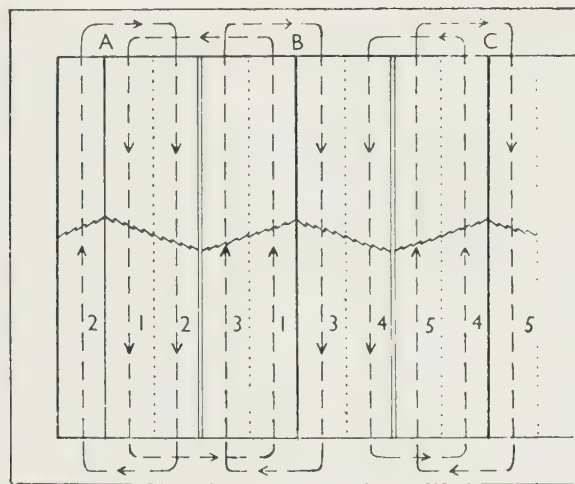


Fig. 4.14 Method of tractor ploughing in lands A,B,C, Ridges.

this method than with any other, apart from round-and-round methods or using a reversible plough.

Setting up tops and making finishes with a tractor plough

The details of good tractor ploughing can only be learned by practice, but one method of starting and finishing that is generally satisfactory may be briefly detailed. The method described is one of many, and other ways may be better for particular circumstances.

Even experts need to mark out the land accurately and to use sighting sticks. To start a top on old turf the front body or bodies may be raised clear of the ground, the rear disc set just below the top edge of the share and a shallow skim 50 mm (2 in) deep cut with the rear furrow only. Then, turning right at the end of the ridge, the plough may be set shallow and level so that the first furrow falls across the original one and half covers it. Turning right again, the plough is again set level and shallow, and the hitch lever adjusted so that the first furrow just meets the first of the last bout.

This procedure leaves a small strip of unploughed land, but it is so well covered that grass or rubbish cannot grow through, and the top is so neat that subsequent cultivations are unlikely to expose the unploughed strip.

To avoid constant alterations of plough settings, all ridges should be set up before ploughing begins.

In making the finish it is essential to correct any irregularities in the width of the unploughed land before the last few bouts. The last two rounds must be ploughed shallower, and on the last bout the strip left should be one furrow width for a two-furrow plough, two for a three-furrow, and so on. For the last stroke the rear disc should be set to run below the bottom of the share, to prevent the plough crabbing; and the plough should be set so that the front body takes a full furrow and the rear one brings up a shallow mould from the bottom of the last furrow.

Square ploughing from centre

A system of tractor ploughing that is popular in some districts for deep work, especially in the Fens, where the fields are well shaped and must be left level, is 'square ploughing'. A small land is first ploughed in the centre of the field. This is made of such a length and width that, when completed, the distances from its sides and ends to the adjacent edges of the field are all equal. Any 'gores' must, of course, be worked out on this land. The outfit then proceeds round and round in a clockwise direction, the procedure at the corners being to lift the plough when it is just clear of the corner, turn the tractor in a small loop anti-clockwise, and drop the plough in to work again just before it reaches the ploughed land on the next side. This procedure can result in very good work; for all the land is turned once and only once, and open furrows, which often cause much difficulty after

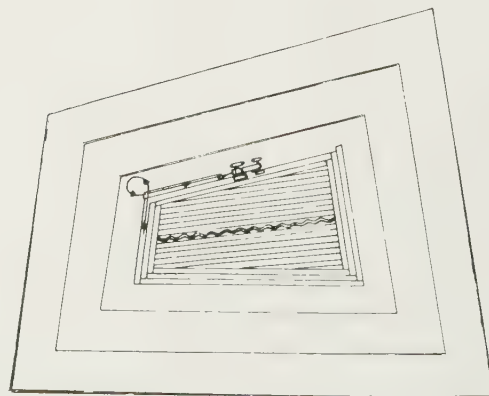


Fig. 4.15 Square ploughing from centre, with loop turn.

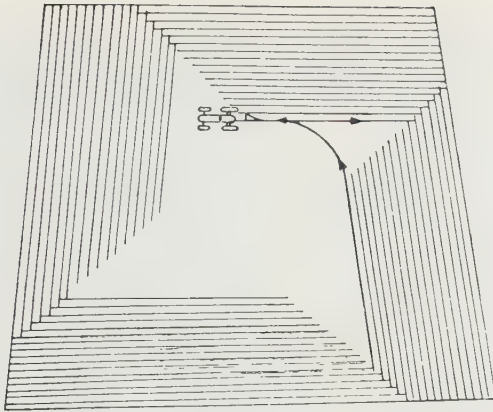


Fig. 4.16 Square ploughing from the outside without cross lands (mounted plough).

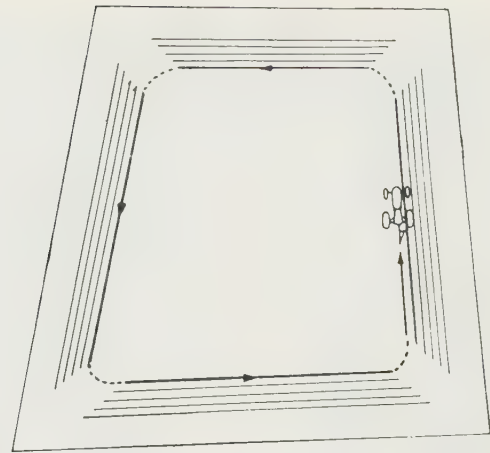


Fig. 4.17 Square ploughing with cross lands.

deep ploughing, are eliminated. Square ploughing from the centre calls for careful marking out of the first-ploughed central piece, and tends, after repetition, to make the field high at the centre and low at the edges. It is therefore necessary to alternate this method with ploughing from the edge to the middle.

Square ploughing from outside (without cross lands)

With a mounted plough, square ploughing from the outside is the easiest and probably the quickest satisfactory method of ploughing. The technique is one which can be applied by a novice. The first operation is to back into a corner and start ploughing at full depth, as near as possible to the boundary, in an anti-clockwise direction. On reaching the next corner, the plough is lifted while it is still just possible to turn easily, and the outfit is then backed into the corner and the next side ploughed. This process is continued, the plough being backed and dropped each time as far into the corner as is necessary to plough all the land. Finally, there remains a piece in the centre which can be squared up and ploughed out as a single land, or in any other convenient way.

Square ploughing with cross lands

With a trailed or semi-mounted plough it is best, when ploughing from the outside, to leave the diagonals unploughed until the finish. The outfit turns the corner

without stopping, the plough being lifted and dropped to leave unploughed strips of a uniform width running from each corner. Finally, these diagonals are ploughed out as single lands. When the first diagonal is being ploughed, the plough is lifted when crossing the second diagonal, so that no land is ploughed twice. In fields of irregular shape, gentle curves can be ploughed round, and a head-land run from any sharp corner to the centre.

This system of ploughing with cross lands is certainly the fastest for trailed ploughs, and probably the fastest for any type of right-hand plough. It requires no marking out, and there is no reason for the tractor to stop while the body of the field is being ploughed. It can, therefore, be strongly recommended. Square ploughing from the middle will, of course, be necessary occasionally, in order to level the field.

Styles of ploughing

The size and shape of the furrow slices are determined by the construction of the plough body and by its setting. A general-purpose plough turns a rectangular slice which remains unbroken in medium or heavy soils. The usual aim with this type of plough is to set up the slices so that they lie at an angle of 45° to the horizontal and leave equal areas of soil exposed on each side of the apices of the slices in the finished work. In order to do this it is necessary to turn a slice in which the width is greater



Fig. 4.18 Types of work (*Ransomes*)

Left: whole work by lea plough on grassland.

Right: broken work by digger plough on light arable land.

Fig. 4.19 Effects of ploughing speed when a multi-purpose body is used on a medium soil in good condition. (*Ransomes*)



than the depth in the proportion 10:7. If the width is relatively less, the slices will stand more upright and there is a possibility of their falling back into the open furrow; if it is relatively greater, the slices will lie too flat.

At various times in the past there has been considerable controversy concerning the merits of different shapes of furrow slice for lea work, especially with regard to the 'crested' style. Crested work is produced by the use of a share having 'up-wing', so that the angle between the coulter and the cutting edge is acute. A similar effect is produced by setting the coulter over to 'under-cut' the land.

The crested slice exposes about 10% more surface to the action of the weather, but the advantages are to some extent discounted by the fact that in ploughing to the same average depth as with the rectangular style more work must be done to plough the same area, and the rate of working is reduced.

The common style of ploughing, when the aim is the rapid production of a tilth, is the pulverised work produced by the digging type of body. In this work the shape of the slice cut is generally rectangular, and the width:depth ratio can be varied over a wide range. An 'under-cut' slice is popular for digging work in some districts. This is produced by using a body which has the shin and coulter set over to make an acute angle with the horizontal share. In some circumstances employment of an under-cut body may lead to more effective burying of rubbish.

Speed has important effects on the type of work done. Where the soil is in a suitable condition for tilth formation, the higher the speed within normal limits, the greater is the pulverising effect (Fig. 4.19). Generally speaking, the

most effective application of power by modern outfits calls for speeds of 4–5 mph (6.4–8 km/h), but such speeds may be too high, with normal mouldboards, for autumn work on wet, heavy land.

The essentials of good ploughing

The rapid development of the plough towards the end of the eighteenth century coincided with the introduction of ploughing matches, at which the skill of ploughmen and the merits of various types and makes of plough could be compared.

The following are among the more important requirements of good ploughing in lands for British conditions:

- (1) The 'top' or ridge should be set up with no unploughed ground beneath it, at approximately the same height as the rest of the work.
- (2) All furrows should be straight and of uniform depth and width. The furrow wall and bottom should be clean-cut.
- (3) All vegetation, manure, etc., should be completely covered.
- (4) The land should be left in the condition required. This may be either well set up with the slices unbroken and firmly pressed together or completely pulverised to full plough depth.
- (5) The furrow ends should be finished off evenly with no packed or unploughed soil, and the lands should be finished off in a manner suited to the style and object of ploughing.

Plough Types and Subsoilers

Tractor plough design has now settled down to a few well-established types. Mounted ploughs have so many advantages that simple trailed types have been superseded. With small mounted ploughs the main trend is towards the simplicity of an implement designed purely for 'draught-control' hydraulics. For larger implements, semi-mounting is common, and hydraulic control normal.

Mounted and semi-mounted ploughs

A few direct-coupled ploughs, when at work, have the depth controlled by levers or screws that operate on a land wheel of some kind; but most small modern ploughs are controlled entirely by adjustments of the linkage mechanism connecting them to the tractor. There is a limit to the size of plough that can be lifted in this way, but there are few implements that cannot be satisfactorily handled in semi-mounted form.

Long, five to twelve furrow semi-mounted ploughs can be hydraulically controlled and lifted out of work at both front and rear. Some are automatically draught-controlled at both front and rear, the action of the rear cylinder being regulated in the same way as that of the main lift-cylinder in the tractor. On another type the front of the plough is controlled by the automatic draught control system, while working depth at the rear is regulated by a screw-controlled depth wheel, which also acts as a hydraulic lift wheel and to assist steering when the implement is out of work. The rear wheel in this case runs on the unploughed land. The plough can pivot around a vertical hinge near the cross-shaft, and as it moves round in relation to the rear of the tractor, the rear wheel is automatically steered in such a way as to limit the width of headland needed for turning the long plough.

Tractors fitted with 'load-monitor' control can employ a special draught-regulating remote cylinder at the rear of long semi-mounted ploughs. This cylinder works in unison with the tractor's main lift ram as described in Chapter 2.

Front-mounted ploughs

The increased opportunities available for use of front-mounted equipment in 'combined' operations have already



Fig. 5.1 Reversible mounted plough with single-component main beam and 5 variable-width pairs of bodies adjustable on the move from 30–50 cm (12 to 20 in) by horizontal ram just above lower hitch pins, acting through bar running parallel to main beam (See also Fig. 4.6). (*Kverneland*)

been outlined. Ploughs need sturdier and more complex front linkages than lighter machines and those with less special setting needs. The main reason for front-mounting a plough is usually to secure maximum ploughing efficiency from a high-powered four-wheel-drive tractor rather than to carry out two or more different operations simultaneously. When using a large rear-mounted plough, a four-wheel-drive tractor needs a considerable amount of front ballast if its front-drive capability is to be effective. Most leading plough manufacturers consider it logical to substitute a two- or three-furrow front plough for the usual cast iron front ballast weights. The front-mounted implement has the disadvantage that it adds to turning and road-use difficulties.

Variable-width ploughs

The introduction of successful mechanisms for hydraulic power-operated variation of plough width on the move constitutes a major advance in the history of plough development. In an early commercial application (Kverneland), the plough bodies are attached to a pivoting parallel linkage which is set in position by a hydraulic cylinder near the headstock. Width of furrow is infinitely variable from 300 to 500 mm; and the linkage is so designed that all bodies operate parallel to the direction of travel at any beam angle, with both front furrow width and rear-wheel setting automatically reset to correct positions. Variable width capability has particular advantages for working up and down slopes, making finishes, and for ploughing round obstacles and up to wavy field edges.

Reversible ploughs

Reversible ploughs save time on marking out and on setting up and closing ridges; eliminate open furrows at junctions between lands; save time on turns, and reduce running along headlands. Level seedbeds are a great advantage for root crops such as sugar beet, and even when grass and grain crops are grown the disappearance of the open furrows leads to easier operation of many implements and machines, and often reduces machine breakages and allows an increased speed of working.

In the past, many distinct types of reversible plough were used; but almost all other types have been made

obsolete by the simplicity of the type which has the right- and left-hand bodies mounted on opposite sides of the main frame, which is turned through 180°. As with right-hand ploughs, the main trend is towards a single diagonal main beam, which is automatically set at the right angle by the turn-over mechanisms. One of the main design problems with reversible ploughs is the heavy lift effort required to raise the two sets of bodies. This leads to semi-mounting of most reversible ploughs with more than four furrows. Nevertheless, direct mounting has special advantages for reversible ploughs because the tractor needs to make a very tight turn to set in beside the work just done.

With long semi-mounted ploughs of either reversible or right-hand type, short-turn facilities in the plough design are highly desirable. With a reversible, it saves time if the plough can be rotated during the turn; strain on the tractor—implement linkage is reduced by a combination of a pivoting headstock with rear-wheel steering. This allows the plough to be rotated as soon as it is fully raised and when the longitudinal axis of the tractor, in making the



Fig. 5.2 A 7-furrow fully mounted plough with headstock adapted to US Category 3 Quick-Hitch on 190 hp four-wheel-drive tractor. With well set skimmers the turf is effectively buried. (Dowdeswell)



Fig. 5.3 Top of range model from Ransomes RT Hydraulic Auto-reset Reversible Plough range with skimmers, shares and knife coulters designed for use in rocky soils. (*Agrolux*)

turn, is approximately at right angles to that of the plough (e.g. Kverneland).

Operation of reversible ploughs

Care must be taken to reverse the bodies only when the plough is raised. Damage to the mouldboards may occur if mouldboards strike the ground. The ploughs often turn with considerable momentum, and it is always necessary to ensure that nobody is standing near the plough when the bodies are reversed.

Swinging beam reversible plough

An implement introduced from America by OPICO in 1990 may be described as a swinging-beam reversible. This implement called a 'Square' plough shows considerable promise (Fig. 5.4). It is reversible but has only one set of bodies, each consisting of a double-ended mouldboard and share 450 mm (18 in) wide and mounted on a beam set in work at typical ploughing angle to the rear of the tractor, alternately to right and left after short headland turns. With the implement raised at the headland, two large rams on the front headstock swing the beam from one side to the other. A third ram angles the front of the implement downwards to secure rapid soil entry at the beginning of each bout. As the tractor wheel enters the



Fig. 5.4(a) Five-furrow swinging-beam reversible plough making clean work of long stubble burying at high forward speed, thereby achieving 180° inversion of the furrow slices in friable soil conditions. (*OPICO 'Square' Plough*)



Fig. 5.4(b) Master 'Switch' plough with reversible non-stick mouldboard covers.

furrow the plough angle returns to level. Power requirement for heavy land is about 35 hp per furrow, and three- to eight-furrow models are offered. The simplicity of the new implement is remarkable. It enables new types of wear-resistant materials, e.g. reversible heavy-duty plastic sheets or ceramic tiles, to be economically used for facing the mouldboards. The implement, with few wearing parts, appears cheap to buy and to run, and reasonably versatile in the types of work successfully undertaken.

The 'Switch' plough (Master Farm Equipment Associates) operates on similar principles to some other

'Square' ploughs and is offered as an import over working widths from 1.2 to 3.6 m (4–12 ft).

The French-made 'Sucomatic' imported by Market Rasen Engineering has one set of swivelling mouldboards, each of which turns individually through an angle that is adjustable to suit soil conditions. Each body incorporates a double-pointed share and also skim coulters which swing and swivel with the mouldboards. The beam also swings through a small angle to assist the change of direction after the headland turns.

Subsoiling ploughs

Tests of the soil condition should be the basis on which the possible effect of subsoiling is judged. Subsoiling is likely to have a beneficial action where there is any 'pan'. On certain types of land a pan is formed just below ploughing depth by the action of the plough slade on the furrow bottom, and this may seriously interfere with plant growth. On other soils, 'iron' pans may be formed in the lower layers of the soil by chemical action. On heavy land, bursting up the lower layers of the soil in dry weather opens up the soil and subsequently has a beneficial effect on drainage and crop root range.

One method of subsoiling is to attach subsoiling tines behind the bodies of an ordinary plough. An under-body subsoiler blade can form a downward extension at the rear end of a short landside (e.g. Dowdeswell). The horizontal L-shaped steel blade running about 150 mm (6 in) below the furrow bottom has a minimum power requirement and saves an extra operation. The device gives best results if fitted to all bodies (See Fig. 5.6).

Automatic plough body reset mechanisms

Where under-body subsoiler blades are fitted or ploughs are used on rocky soils, automatic reset mechanisms are increasingly used to reduce breakages and save time. Reset mechanisms vary considerably in objectives and detail of design.

A two-stage mechanism (e.g. Dowdeswell) employs a six-ball pivot system to give second-stage relief not only parallel to the direction of travel but also, if needed, at an angle up to 60° on both sides to give protection from large rocks lying mainly to either side of the share point.



Fig. 5.5(a) Double-link six-ball pivot auto-reset overload release showing high-lift action — position C of left diagram in Fig. 5.5(b).

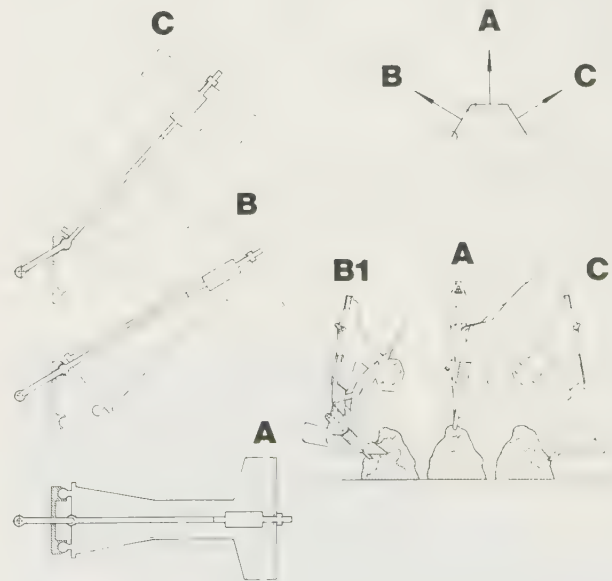


Fig. 5.5(b) Diagram showing action of double-link six-ball pivot release system.

Left: Front anchor point well forward gives rapid reduction of point load between positions A and B; high lift to C gives additional margin of relief.

Right: Body can swing in three directions: vertical (A); to land from obstacle on wing side (B1); and from land (C) reacting to rock mainly on that side. (Dowdeswell)

The hydraulic reset mechanism incorporates a nitrogen accumulator to provide the required 'spring' force in the hardest conditions. An advantage is that the hydraulic systems of all bodies are interconnected, and a single adjustment from the tractor hydraulic system gives the same relief pressure to all bodies.

Soil looseners and subsoilers

Current trends in use of soil loosening and subsoiling implements and attachments are influenced by some research and a steadily increasing user interest and experience. Most medium-sized and large-scale farmers and contractors now have wheeled tractors with sufficient power and pull to operate implements capable of providing a loosening effect across the whole of a reasonable working width of 2–4 m. A sensible aim is gradually to increase working depth rather than to use widely spaced narrow tines at a great depth. Multiple legs are commonly staggered on a two-beam implement; some are arranged in a single line of blunt arrow shape.

One of the contributions of research is to emphasise the effectiveness of slim legs of high-grade steel, fitted with narrow replaceable hardened chisel points running well ahead of the replaceable shins. Replaceable wings may be fitted well behind the points, reducing pressure on the blades and avoiding or minimising bringing intractable clods or large stones to the surface (Fig. 5.8). Tines for deep work may be attached to the beams via a sturdy

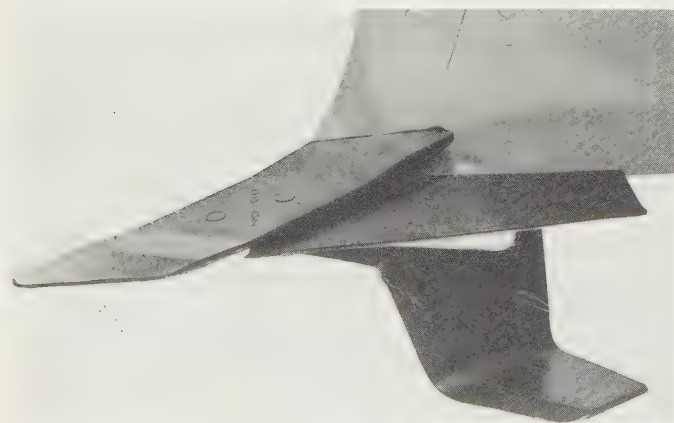


Fig. 5.6 Under-body subsoiler blade. (Dowdeswell)

vertical pivot which enables the leg to swivel to avoid excessive localised resistance. Relief from immovable rocks is usually provided by a horizontal pivot pin and a lower shear pin which allows the leg to swing back and up after shear pin failure. Power requirement in typical conditions is about 25 hp (19 kW) per leg. It is economic in power use to carry out subsoiling after a fast shallow stubble cultivation. In such conditions use of a heavy crumbler roller at the rear can assist depth regulation and preparation for early drilling without undesirable surface consolidation.

Early attempts to reduce draught and improve effectiveness of subsoilers by employing a pto drive to reciprocate the points underlined the need for strength and durability in the main components and good engineering design of the eccentric mechanisms. Experience with well proved mechanisms (e.g. McConnel) shows that the power drive is most useful in very hard conditions. As with all subsoilers, a reasonably low rate of wear on points and shins is essential, and depends primarily on a streamlined design and on use of hard-wearing materials. Research and development work on early McConnel Shakaerator tines at Silsoe College, involving a change from a fabricated welded shin to a cast one, resulted in smooth patented interlocking between the bottom of the shin and the tail of the point, thereby securing appreciably reduced draught and easy replacement of the wearing parts when needed. A bonus was provision of choice of two angles of lift from the point and integral wings by simply turning the point over.

A subsoiler design of outstanding simplicity and durability, yet with flexibility features covering normal needs, is illustrated in Fig. 5.7. The tine-carrying part of the frame of the model shown normally carries the three tines shown: wider models of the same general construction carry up to seven tines. The rear part carrying a scraped 350 mm (14 in) diameter rear crumbler with sturdy teeth is hinged and adjustable by screw type turnbuckle to provide simple setting of tine working depth. In normal conditions it provides a free-working tilth on the surface.

The 'Paraplow' was originally introduced by Howard in collaboration with ICI in a form very similar to that of a single-beam plough was widely reported by independent investigators to have been successful in restoring productivity to badly poached and compacted pastures, without destruction of the indigenous sward. A controlled trial established in 1986 by the Environmental Sciences



Fig. 5.7 3 m model mounted subsoiler with tine clamps easily adjustable along the main beam to suit individual and varied needs. All tines and teeth have shear bolt protection: tine holes are lined with replaceable hardened bushes. Points and shins are quickly replaceable by removal of two roll pins, and weld-on tips are available for the low-lift points. (*Simba 'Flow-King'*)

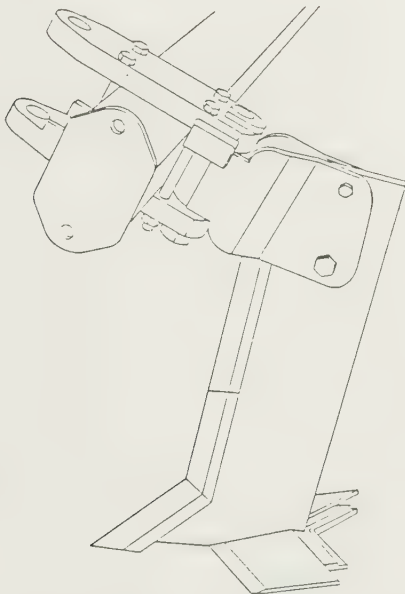


Fig. 5.8 Basic components of sub-tiller with (patented) angled swivelling tine support; shins with tapered cutting edge running the full length of the leg and point; and wings attached towards the rear of the leg. In normal conditions subsoil loosening results in minimal raising of stones or clods into the surface layers. (*Spaldings 'Flatlift'*)

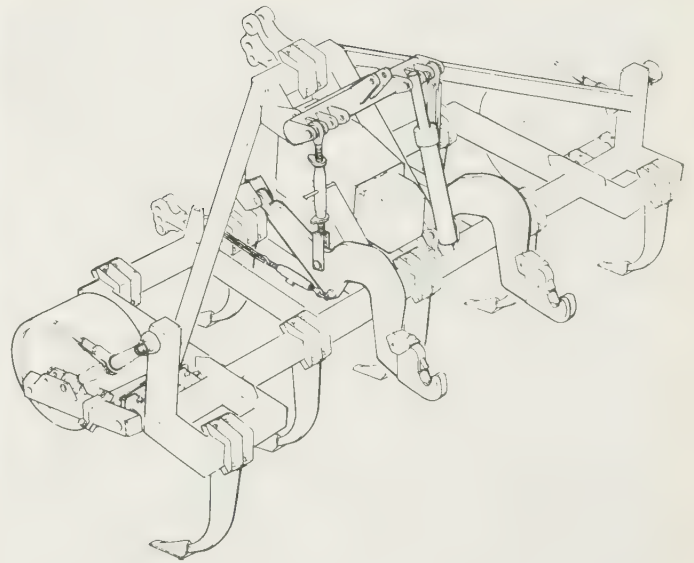


Fig. 5.9 Subsoil loosener with pto drive which provides vertical reciprocation of the whole implement. The power-lift three-point linkage shown at the rear can be used for other implements including a heavy crumbler roller or pto-driven machine, receiving its drive from the rear end of the subsoil loosener drive shaft. (*McConnel 'Shakaerator'*)

and Crop Production Departments at the West of Scotland College showed rapid improvements on heavy poorly drained soils under a high nitrogen regime and subjected to rotational grazing by the large Auchincruive dairy herd. Mole draining, use of a conventional subsoiler and the Paraplow were all found beneficial compared with the untreated control plots in a properly replicated trial with randomised treatments.

A development of considerable promise is a new Howard model (Fig. 5.11) with four legs, two right-hand and two left, arranged on a sturdy cultivator type frame so that the considerable side forces involved are evenly balanced. The implement has little tendency to bring clods to the surface in normal conditions. Tractors need to be hitched so that the wheels do not run on the edge of the previous bout. It is essential to use the inclined corrugated discs which are part of the standard equipment, and to set them as advised to reduce unnecessary draught and wear.

With all types of subsoilers it is advisable to remember that surface trash between legs and frames can make the

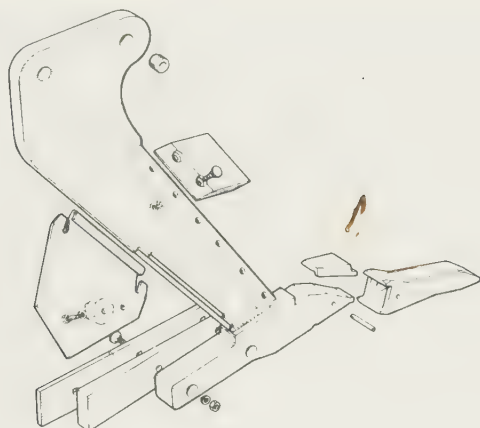


Fig. 5.10 Diagram showing detail of original 'Paraplow' leg, with renewable shin plates; easy-fit reversible point providing working depth to 40 cm (16 in); renewable landside; and adjustable shatter plate which can be set to increase lift in moist conditions. For work in grass, soil should be moist below and firm on top, and time of year early spring or autumn when drought is unlikely. Overall rolling to seal slits at surface should follow. (*Howard-Farmhand*)

maximum working depth attainable appreciably less than the distance between the bottom of the frame and the working points. The Paraplow has replaceable wearing plates on shin and landside and an improved easy-fit type of point. An adjustable hinged shatter-plate attached behind the lower part of the leg permits regulation of the amount of loosening attempted (see Fig. 5.10).

Disc ploughs

Disc ploughs bear little resemblance to mouldboard ploughs, for a large revolving concave steel disc replaces the share, coulter and mouldboard. The disc is set at an angle to the line of travel, and it turns a furrow slice to one side with a scooping action. The usual size of the discs is about 610 mm (24 in), and these will turn a furrow 250–300 mm (10 to 12 in) wide. With trailed implements the discs are mounted on a heavy frame, and the large amount of side-thrust due to the pressure of the soil is carried by the three wheels, the two furrow wheels being inclined in a suitable direction to withstand it. The wheels are often weighted to assist in the penetration of hard land, since the discs themselves have little 'suction'.



Fig. 5.11 Up-dated balanced 'Paraplow' with two right and two left-hand legs mounted on opposite sides of the sturdy mounted frame. Two depth regulation wheels are mounted just forward of the main beam. All legs have a long vertical length at the top and an automatic break-back device for stony conditions or deep work. The discs also incorporate a spring release. (*Howard-Farmhand*)

The disc angle (horizontal angle between plane of disc face and direction of travel) is usually just under 45°, while the tilt angle is usually 15–25° from the vertical and is easily adjustable. As a general rule, draught is lowest at a disc angle of about 45°, and up to this angle, increasing the angle tends to increase penetration. Increasing the tilt angle from 15° to 25° increases the draught slightly and tends to reduce penetration, but assists in turning the furrow slice effectively. Correct setting of the scraper assists in inverting the furrow and burying rubbish.

Disc ploughs suitable for mounting on the hydraulic lift linkage have now been developed – largely in response to the needs of farmers in countries where mouldboard ploughs are seldom or never employed. Chief advantage of the mounted implement is its manoeuvrability and ease of transport. A disadvantage is the fact that it has to be made reasonably light to facilitate lifting. Disc ploughs are well adapted to ploughing extremely hard soils. They also deal with certain types of sticky soil better than the mouldboard plough, and will work in long, loose rubbish where no mouldboard plough will run. They are widely used in America, Australia and South Africa, but seldom in Britain. They cannot satisfactorily replace the mould-

board plough for ordinary purposes in this country owing to their failure to bury rubbish completely or to cut all the ground.

'Stump-jump' disc ploughs of Australian origin have been used successfully for very rough work such as preparing land for reseedling where there are tree stumps, tree roots or large rocks to contend with. The stump-jump disc plough will stand up to work that would ruin any mouldboard plough, however strongly constructed.

The 'disc tiller' (British Standard term), 'harrow plough', 'vertical-disc plough' or 'poly-disc' has a number of discs mounted at a uniform spacing of 200–250 mm (8–10 in) on a common axle or gang bolt. The disc angle is usually about 40–45°, and there is a considerable range in disc sizes. This implement has an action intermediate between that of the true disc plough and the disc harrow. It is commonly employed, with a seed-box attached, for

ploughing and seeding in one operation in the drier parts of the Canadian Prairie Provinces and similar regions of the United States.

A popular implement is the 'discer', usually very wide, with moderately small discs mounted in gangs of six and capable of independent vertical movement on the main frame. This implement normally works only about 75 mm (3 in) deep, and has a seed-box attached. The power lift raises the discs and shuts off the flow of seed, but does not raise the whole frame of the implement as it does in the case of the disc tiller.

Reference

Gill, W. R. and Van Den Berg (1967) *Soil Dynamics in Tillage and Traction*. US Department of Agriculture. Handbook No. 316.

Implements for Seedbeds and Inter-cultivation

Developments in tillage practices briefly surveyed in Chapter 3 have led to an array of equipment which does not conveniently fit into categorisation under the headings 'primary' or 'secondary' cultivation. The equipment dealt with in this chapter is arranged in main groups as follows:

Without pto drive:

Tined cultivators, including multiple-depth and combination implements;

Harrows, tined, disc and rotary ground driven;

Cultivator-harrows, including two-rotor differential speed types;

Rolls, furrow presses and rotary crumblers.

Pto-driven rotary cultivators and power harrows:

Some are used as the basis for combination fixed tine and power-drive cultivator/harrows and for cultivator/drill combinations.

Implements for row crop cultivation:

Ridgers, bed-makers, inter-row grubbers, hoes and thinners.

There are no essential differences between deep cultivators and subsoilers on the one hand and shallow cultivators and harrows on the other. Cultivators are normally for deep work, compacted soil and large clods while harrows are expected to provide a fine surface tilth; but some power harrows can tackle deep work in compacted soils or intractable clods. So the terms cultivator and harrow are very loosely used, and some tined cultivators are called 'chisel ploughs'.

Engineering studies on 'secondary' cultivation mechanisms begun by Silsoe Research Institute in 1987 soon showed significant differences between power-driven mechanisms and draught implements in the depth of cultivation and the direct implement energy use. On heavy clay soils depth of work at 75 mm by pto powered

machines tended to be 2–3 times greater than for two passes of comparable draught implements where depth of work ranged from 30 to 60 mm. On lighter soils, where energy input levels were approximately half the values for the clay soils, working depth for the pto-powered machines was 100 mm, compared with 60–100 mm for the draught implement.

There are, of course, many other factors than depth and uniformity of cultivation, and energy inputs to be considered when deciding choice of seedbed preparation equipment; and among these timeliness and reliability in achieving desired sowing dates are outstanding. The figures quoted should therefore be treated partly as a reminder to practical users of the value in particular adverse working conditions of simple standby equipment which may help in completing sowing to a good timetable at reasonably low operating cost.

Cultivators

A new development stimulated by the need for fast and fairly fool-proof stubble breaking with chopped straw incorporation is based on a heavy draught implement consisting of a partly articulated universal frame capable of carrying effective discs at the front, three or four subsoil tines with points slightly to rear of the transport wheels, and a fully adjustable toothed and rear-scraped crumbler roller at the rear (Fig. 6.1). The usually cut-away and widely spaced large diameter discs easily invert and bury a reasonable depth of trash and reduce draught of the subsoil tines. The whole implement has hydraulic depth regulation via the transport wheels.

In other circumstances, with less emphasis on trash burial, a lighter implement and closer spacing of the slim deep-working legs and narrow points may be preferable (Fig. 6.2).

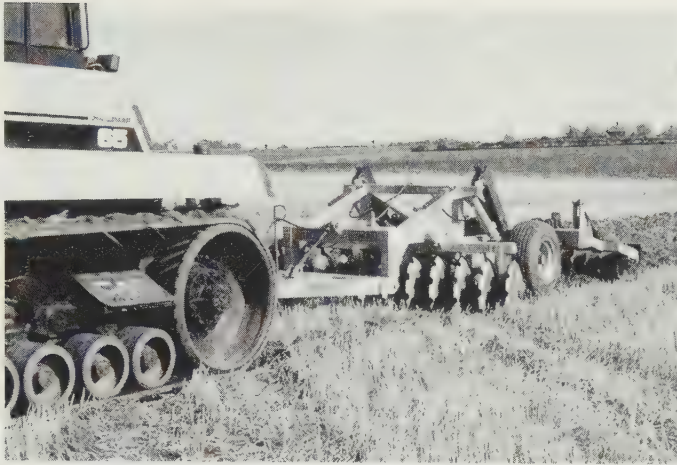


Fig. 6.1 Universal articulated frame capable of carrying a range of easily interchangeable components, enabling a number of linked tillage operations to be carried out by a powerful tractor in one pass. The trailed main frame can be pre-set for working depth and pitch. The implement is shown with a popular arrangement comprising a front row of heavy large-diameter discs, cut-away as shown or plain with added peripheral knives, widely spaced to invert and bury trash; followed by a line of three or four subsoil tines; and a large-diameter fully adjustable toothed packer roller with scrapers at the rear. Depth control is mainly by hydraulic adjustment of the transport wheels. The combination illustrated is well matched with the rubber-tracked Caterpillar Challenger 65. (*Simba 'Mono'*)

Cultivators for light or medium duty tend to use some type of spring tine or spring-mounted tine. A common type for light cultivation has a flattish section with the width more than four times the thickness from front to back. Such tines are made substantially of C-shape, but with a reverse bend at the top where the tine is fixed to the implement frame (Fig. 6.4). Another type of spring tine has a section that is almost square. This type is often formed with two complete loops between the top of the C and the fastening to the implement frame. This latter type is generally intended for deeper work (Fig. 6.5).

Tines with right- and left-hand spirals are provided and these should be used in equal numbers on the right and left sides of the cultivator to keep the implement running straight. One type of spring tine consists of three leaf-type springs, of which only the outer is clamped to the body. In light work only the outer spring is operated,

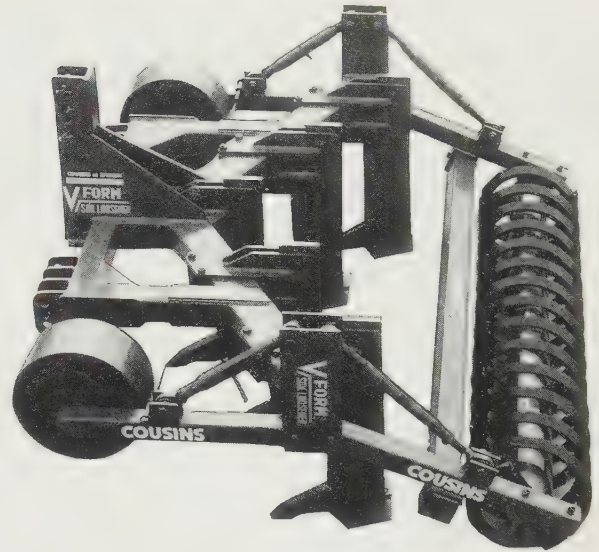


Fig. 6.2 Medium duty V-form linkage-mounted 2.25 m five-tine soil loosener complete with Spiroller™ solid coil crumbler roller. Turnbuckle adjustment is provided to 450 mm diameter by 200 mm wide depth wheels and to 450 mm diameter Spiroller coil. (*Cousins*)

while in heavy all three springs come into operation, so that springiness is provided in all types of work.

In addition to typical C-shaped tines, there are types which incorporate a stiff straight section which is usually approximately vertical, and with the help of depth wheels makes the tines suitable for a fairly wide range of depths. In addition there may be a facility for angling the tines back about 30° to widen the range of practical uses (e.g. Vaderstad 'Agrilla').

Many types of cultivator tine depend for their spring action on a separate coil spring, often a fairly short compression type, suitably housed between the implement frame and top of the tine. Some manufacturers offer tines with a pair of long extension springs. This type, which can permit a big movement of the tine, is well suited to work among tree roots or in rocky land, where it is desirable to permit the tine to move back and ride over the obstacle when necessary.

When spring tines first became widely used with high-powered tractors there were many breakages. Research showed that properties involved, in addition to the obvious

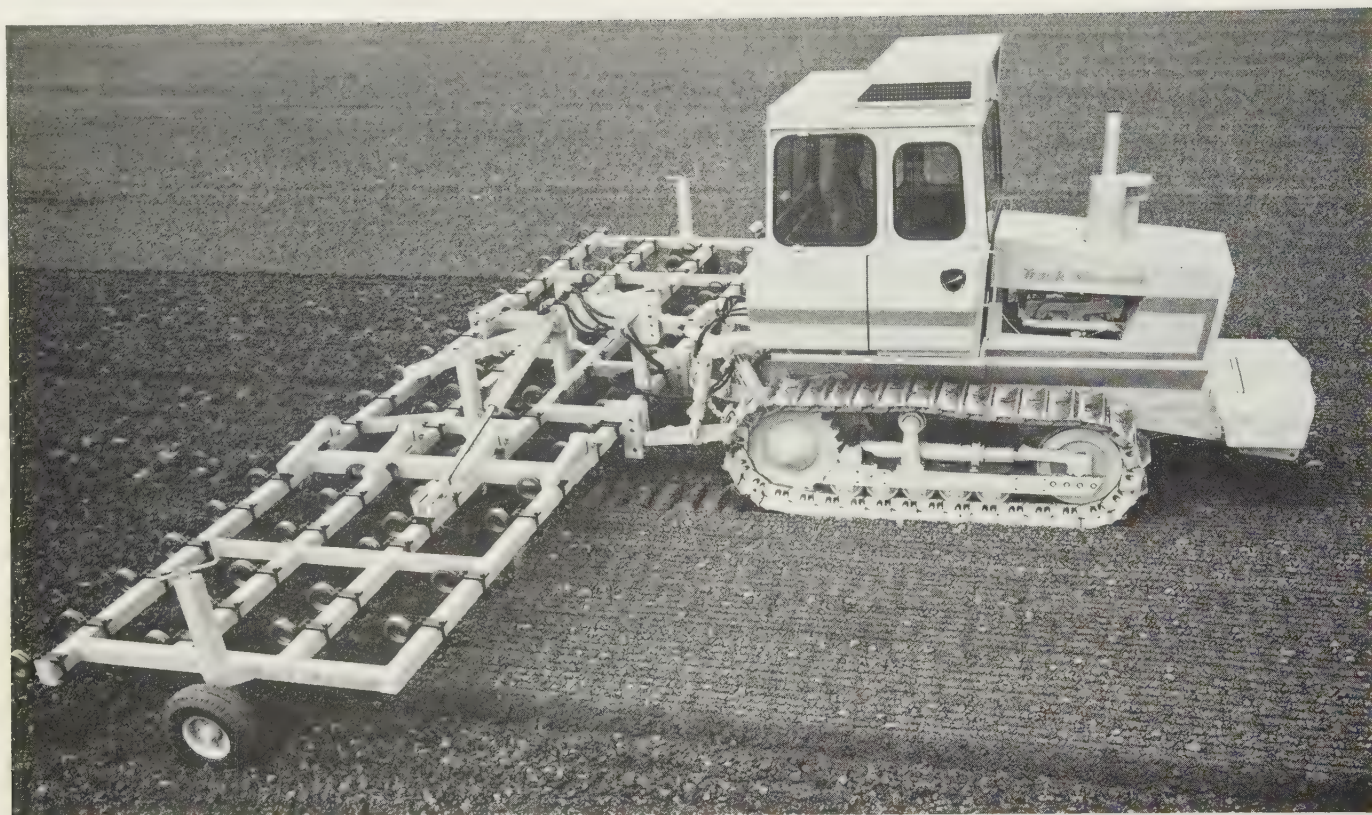


Fig. 6.3 The hydraulic-folding mounted cultivator engaged in seedbed preparation with heavy-duty double-coil spring tines is matched to the 136 bhp turbo-charged tracklayer, with a single-lever power steering. (*Track-Marshall*)

ones of hardness and tempering (see Appendix 4) included the surface finish. A smooth finish produced by shot peening was found of value in extending tine life under repeated bending stresses.

The shares or points used on cultivators are very varied, ranging from reversible points for average work to strong narrow points for deep work and broad A shares for shallow work. There are also special blades for cutting thistles, and knives for cutting matted turf. The points and shares are generally made of steel, but some of the very heavy cultivators have massive chilled cast iron or cast steel points. BS 2659: 1969 specifies standard dimensions for the lower parts of cultivator tines, and helps to secure interchangeability of points over a wide range of implements. For easy penetration of compacted

soil, with low draught, the points of cultivator tines (or heavy harrows) need to be set at an angle in the region of 45° . It is usually convenient to change the angle to near-vertical at the top to secure more surface clod-shattering and less surge with draught-control systems.

Cultivators usually have two or three rows of tines which are 'staggered' to provide a clearance between adjacent tines through which clods and rubbish can freely pass.

Draught control does not usually provide effective depth regulation for shallow working, so it is useful to have depth-regulating wheels or rollers available.

Some spring-tine cultivators incorporate an automatic self-levelling device which assists in maintaining a uniform working depth on flat or undulating ground. The method



Fig. 6.4 Mounted cultivator-harrow for high-speed work with four rows of flat-spring-top tines designed for intense vibrating action and Rotoflex attachment for straw breakdown and mixing. (Kongskilde 'Vibraflex')



Fig. 6.5 Mounted all-draught cultivator for one-pass seedbed preparation comprising heavy-duty front levelling board adjustable for pitch and designed to cut or crush surface clod; two fully adjustable crumbler rollers of toothed and scraper type. The 350 mm (14 in) diameter front one carries much of the implement weight and is an effective clod crusher; the second of 275 mm diameter levels the soil surface to give reasonable firmness at sowing depth. Two banks of two staggered rows of heavy-duty double-coil spring tines (or rigid straight type) are attached (1) between levelling board and front packer-roller, and (2) between the two packer-rollers. (Simba 'Top-Tilth')

of doing this varies. In some implements the headstock position is varied through a spring-controlled system of cranks and levers.

The term 'chisel plough' is indiscriminately applied to any type of cultivator that is capable of working compacted soil at moderate depth. The tines may be spring, spring mounted or rigid, the main feature being wide tine-spacing and ability to work fairly deep in most soil conditions if required. Deep-working tines for use in rocky soils are available with various types of overload release mechanisms. Simple tension springs may be replaced by a carefully designed automatic reset device. One type has a large bow-shaped spring and a linkage with sufficient movement to let the point ride over a large immovable rock and return to work quickly after passing it. Combination implements of various kinds have shallow working tines at the front and deeper working tines at the rear. Some implements have three lines of tines with two or three subsoiling tines in the last row.

Conditions for use of cultivators vary so widely that it is often useful to be able to change the working width. This can be done in an economic way by provision of a central unit of medium size and one or two smaller sections that can be added to make the implement wider when conditions are easier.

Harrows

Harrows are employed for a great variety of purposes such as the preparation of seedbeds, the covering of seeds, the destruction of weeds and the aeration of pastures. Many types and sizes are used for carrying out these widely differing functions. The most common and simple type is that with a zig-zag iron frame and rigid teeth. The range of zig-zag tractor harrows may be conveniently specified by reference to the thickness of the teeth, which usually ranges from about 12.5 mm ($\frac{1}{2}$ in) square to 19 mm ($\frac{3}{4}$ in) square.

Seeds harrows are light implements with straight, closely spaced teeth, about 100 mm (4 in) long. Owing to the zig-zag construction of the frame the teeth are staggered so that those at the rear do not follow in the tracks of the front ones. These implements are employed for the final touches in the preparation of fine seedbeds and for covering seeds after the drill. Sets of seeds harrows and slightly heavier 'light' harrows from 6–9 m

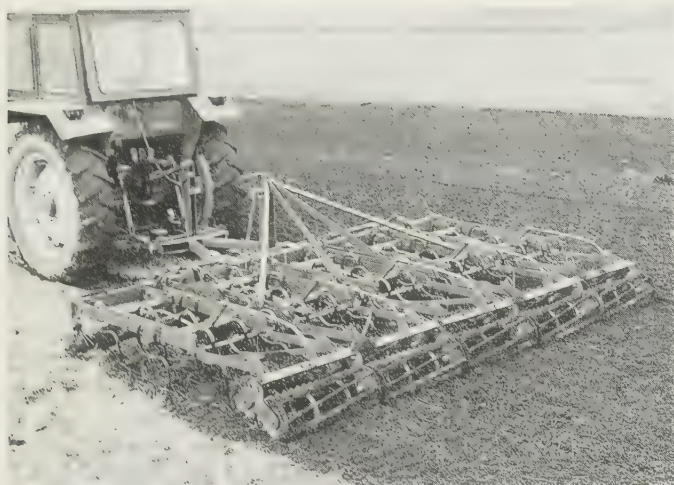


Fig. 6.6 Wide mounted cultivator harrow with S-type lines, having spring-assisted hinge-folding wings and light crumbler roller. (*Kverneland Futura*)

(20 to 30 ft) wide are easily within the capacity of small tractors. When they are used for covering seeds, harrows are frequently hitched directly behind the drill.

The handiest equipment for this purpose, however, is a device supplied by the drill manufacturer and usually consisting of a row of spring coverers which can be adjusted to suit the conditions.

Medium tractor harrows, with teeth 16 or 19 mm ($\frac{5}{8}$ or $\frac{3}{4}$ in) square, are used for such purposes as the preparation of seedbeds, mixing of fertilisers with the soil and spring cultivation of autumn-sown corn. The wider the implement, the more essential it is to have adequate arrangements for transport. Mounted implements up to about 8 m wide, suitable for use with tractors of 40–50 kW, may be carried on a frame provided with hydraulic folding of the outer sections to give a transport width of about 3 m. Heavier and wider harrows for use with tractors of about 75 kW may be semi-mounted. One type provides for power lifting of the harrow sections on to a wheeled frame, the wings of which can be manually rolled into line behind the centre sections (e.g. Parmiter, Fig. 6.7).

A favoured method of construction for heavy harrows is with round-section teeth that can be knocked down to compensate for wear and may have provision for adjustment of the angle of the teeth. This type is often used in conjunction with an adjustable steel or steel-edged wooden scrubber board at the front for producing level

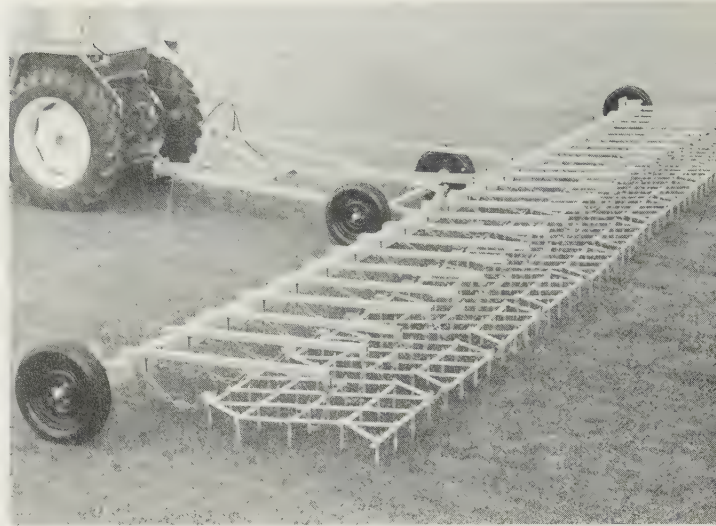


Fig. 6.7 Semi-mounted 12-section (12.5 m) medium zig-zag harrow with 16 mm ($\frac{5}{8}$ in) tines. An external hydraulic ram raises harrows from working to vertical position. The frame is then folded by hand, and the wheels at rear are turned 90° and locked in transport position. (*Parmiter*)

seedbeds. The heavier the work done, the more essential it is to ensure that harrows run without bounce (Figs 6.8; 6.9). Construction features include departure from the principle of independently attached sections, and linkages designed to assist even running. In the Agrolux 'Contour' linkage each section is controlled by two free lower links

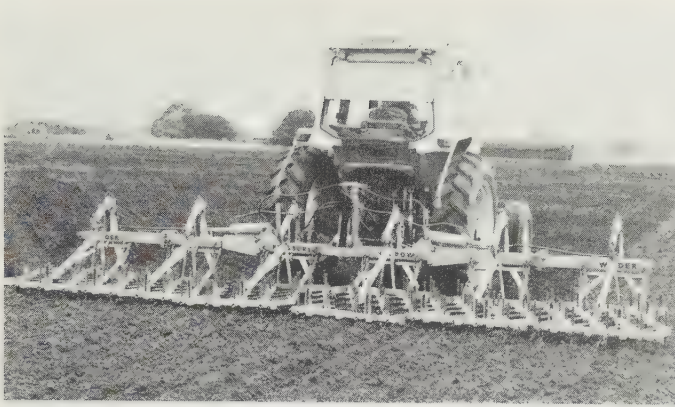


Fig. 6.8 Six-section (6.8 m) mounted zig-zag heavy harrow with adjustable-depth tines, hydraulic folding and closed hydraulic 'pressure' linkage system for connecting individual sections. (Agrolux 'Contour')

and one upper link incorporating a hydraulic cylinder, the upper end of which is connected to the implement drawbar. All of the implement's cylinders are interconnected by flexible hoses in a closed hydraulic circuit. With the harrow on level ground at normal working depth each of the ram cylinders is half-filled with oil. If an individual section encounters very high land, some oil is pushed out of its top link into the cylinders connecting adjacent sections, while if it drops into a low area the converse happens. The damping and limitation of flexibility assist in securing even running and sufficient flexibility to ensure that low areas are cultivated.

Combination cultivators

Now that tractors commonly have sufficient power to carry out all necessary pre-drilling cultivations over a width up to about 5 m in one pass, many manufacturers offer combination implements consisting of several independently adjustable components from front to rear. With wide implements it is also necessary to allow for independent floating of adjacent sections to ensure that work is at a constant depth over undulating surfaces. Typical implements have powerful clod-crushing and levelling devices at the front (adjustable boards, inclined

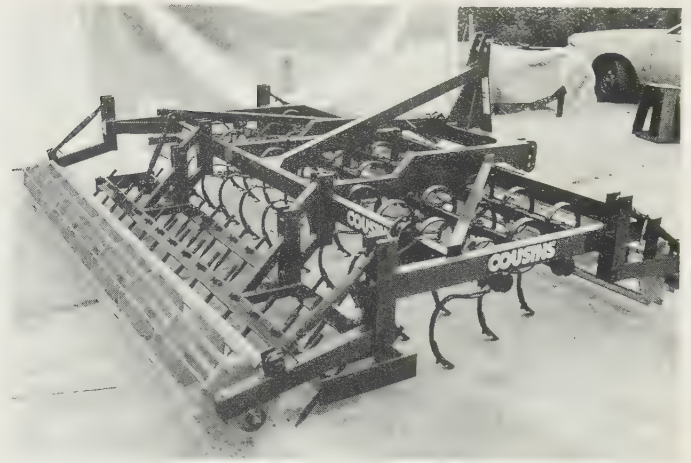


Fig. 6.9 Medium weight mounted combination harrow designed for level seedbed production in one or two passes. Leading crumbler barrel (heavy-duty type) is followed by three rows of S spring tines; two rows of angled-back harrow tines and rear crumbler barrel. Both crumblers are turnbuckle-adjustable and the S tines can be angled back by screw adjusters. An alternative Spiroller™ can be fitted at the front. (Cousins)

fin, crumbler rollers); many rows of staggered tines forming the main section; and depth-adjusting and firming crumbler rollers at the rear. It is likely that this trend towards combination implements will be further developed.

Spring-tined harrows

The spring-tined harrow is really a light cultivator which can be adjusted to produce very variable effects. The tines are fitted to axles which can be partially rotated by means of a lever or screws. With the implement working very shallow, the points are almost vertical and the action is that of a light harrow that does not penetrate to the lower layers. When set in an intermediate position the points are inclined, and the action is that of a light cultivator. At full depth the points are almost horizontal and the soil is deeply stirred. A modern implement designed for tractor mounting uses a linkage-mounted frame of width suitable for 2, 3, 4 or 5 9-tooth sections, with folding for transport in the larger sizes (e.g. Parmiter).

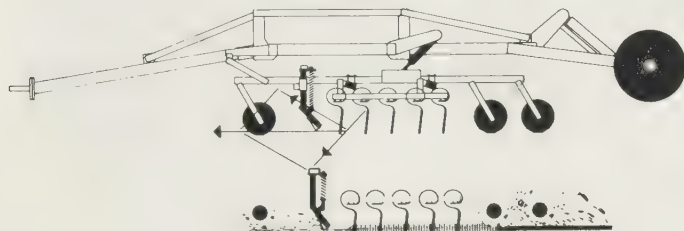


Fig. 6.10 Trailed seedbed preparation cultivator comprising rotary crumblers (front and rear); spring-loaded levelling bar; and a large number of semi-rigid almost straight tines with renewable points inclined slightly forwards. The soil-working tools are all mounted on one of a number of independently depth-regulated sub-frames, which are linked to one another by a closed hydraulic circuit ensuring that an even pressure is applied to all sections. The drawing shows linkage of a single section to the main frame and the general shape of the tines. Arrows indicate method of maintaining uniform working depth. Frame weight is applied through individual series-connected hydraulic cylinders to centres of each individually floating section by equal forces applied at downward angle of approx. 45° ; the front draught links are inclined downwards and rearwards giving resultant horizontal draught forces at depth depending on both soil resistance and ground contours for each floating unit. Two or three longer tines can be fitted in the sections running behind the tractor wheels to help to eradicate wheelmarks. (*Kongsilde 'Germinator'*)

Rotary weeders

A typical rotary weeder or rolling cultivator consists essentially of narrow ground-driven spiked wheels, with curved teeth which have a slicing action. Diameter is

usually about 508 mm (20 in), and the wheels are mounted 150 mm (6 in) apart on a transverse shaft, in tandem with a second gang so as to provide for working the soil in lines 75 mm (3 in) apart. They are chiefly used to break the surface between row crops in conditions where there is a tendency to capping, but may also be pulled in a reverse direction to give light packing just below the surface. This implement is common in America and in some European countries, but is seldom seen in Britain.

Chain harrows

Chain harrows have no rigid frame. The most valuable types combine the advantages of flexibility and of teeth that will effectively penetrate into the soil. Such harrows may often be used with good effect on pastures as well as on arable land. On the heavy types of flexible harrow, the knives may be set so that different effects are obtained by turning them over and using the other side. Some harrows have turf blades on one side and arable land tines on the other.

Disc harrows

Disc harrows have a number of saucer-shaped discs mounted on one, two or more axles, which may be set at a variable angle to the line of draught. The discs are generally from 457–610 mm (18 to 24 in) in diameter, but heavy types, widely spaced, increasingly used for a



Fig. 6.11 Ransomes 'Incorporator' tandem disc harrow with hydraulic depth control/transport wheels and manual folding. (*Agrolux*)

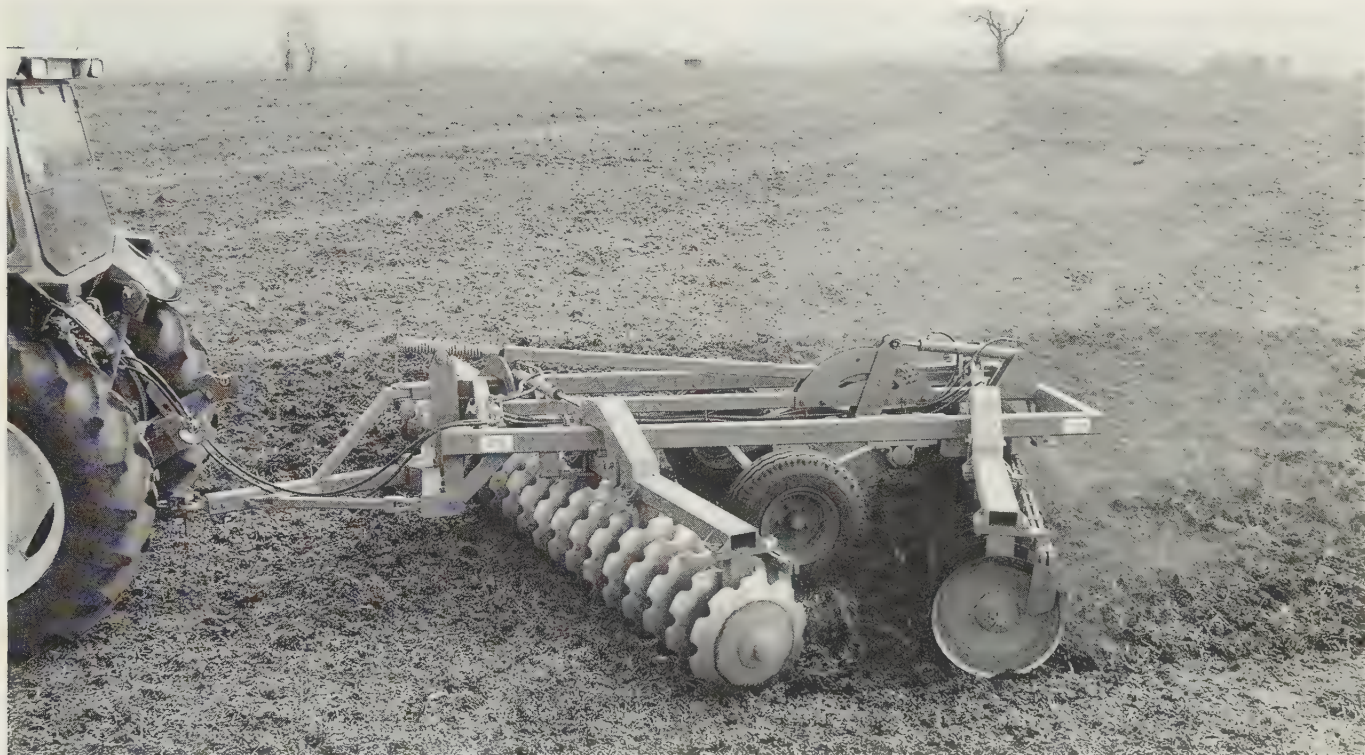


Fig. 6.12(a) Trailed heavy duty offset disc harrow equipped with cutaway discs in front row and plain at rear, making second pass across the work on straw incorporation. The outer disc gangs of the 4.5 m implement are hydraulically folded upwards for road transport. (*Dowdeswell 77 Series*)

Fig. 6.12(b) Shows 4.5 m hydraulic folding model reduced to 2.52 m for transport.



Fig. 6.12(c) Heavy-duty Parmiter UTAH 450 with cut-away discs and hydraulic controls for depth of work and road transport as used for work on stubble breaking on dry land. (*Parmiter*)



first stage of incorporating unchopped straw, are available with discs 10 mm thick and 800 mm diameter (32 in) spaced at 400 mm (16 in), or, rarely, 900 mm (36 in) diameter, 12 mm thick (blade weight 400 kg) and spaced at 500 mm (20 in) (e.g. SIMBA). The common sizes rotate as the harrow is pulled along, and their action on the soil is not unlike that of small digging-type ploughs. The precise action, however, depends on the size of discs, the depth of work and especially upon the angle at which the disc gangs are set relative to the line of travel. If the disc gangs are set perpendicular to the line of draught, penetration is shallow, but the surface of the soil is pulverised and the lower layers are compressed. The penetration of disc harrows is achieved by virtue of the weight of the implement, and may be increased by the addition of extra weight to pans attached to the frame for that purpose. When maximum penetration is desired, the gangs should be set with the forward edges of the discs parallel to the direction of travel. Penetration is also assisted by a low hitch point, a low forward speed and by sharpening the discs if necessary.

Cut-away discs penetrate better than plain, and for this reason there is an increasing tendency to use them for the front gangs of tandem implements. As a general rule, tandem implements are arranged to work with the gangs set at angles varying from about 15° to 25°. It is often desirable to set the front gangs at a greater angle than the rear ones. A typical hydraulically controlled 3 m (10 ft) implement has a fixed working angle of 20° for the front gangs, which are cut-away; and the rear gangs, which are fitted with plain discs, may be set as 12°, 16° or 20°.

Transport problems with heavy implements of semi-mounted or trailed type may be solved by the use of pneumatic-tyred road wheels and external hydraulic lifting cylinders to raise the discs or similar cultivation equipment out of work. With trailed implements advantage may be taken of weight transfer to the tractor wheels through 'pressure control' (Massey-Ferguson) if the necessary strong frame and linkage are provided. 'Load monitor' control (Ford) by means of an external cylinder can also provide operational advantages. Very wide implements used with high-powered tractors may be fixed to a frame which can be folded for transport.

The chief wearing parts are the bearings and the discs themselves. The discs should be made of properly heat-treated high-carbon steel. BS 2687:1972 prescribes

dimensions and minimum material standards for agricultural discs, including those of disc harrows.

Modern implements with positive hydraulic depth control can be very useful for primary cultivation where a well-worked seedbed of moderate depth is required, or where trash needs to be worked into the soil. Their main competitors are tined cultivators and pto driven machines including rotary cultivators and power harrows.

Ground-driven rotary harrows

One type of harrow (Fig. 6.13) designed for mounting on the three-point linkage has rotary blades carried on two, four or six shafts arranged at an angle, somewhat like the disc gangs of a tandem disc harrow. Each rotary cutter consists of two double-ended blades arranged at right-angles in the form of a cross. The knives have sockets shaped to take the axle shaft, and are separated from the next set by spacers. Working depth is generally shallow, but may be up to 180 mm (7 in). Best results are obtained at 5–8 mph (8–13 km/h). The implement has a pulverising effect on the surface layers and is self-cleaning. Mounted implements with a concertina-type frame, which can be easily opened up for work or compactly folded by lowering and backing for transport, can be successfully used for stubble cultivation (e.g. Falcon/Wartsila 'SAMPO').

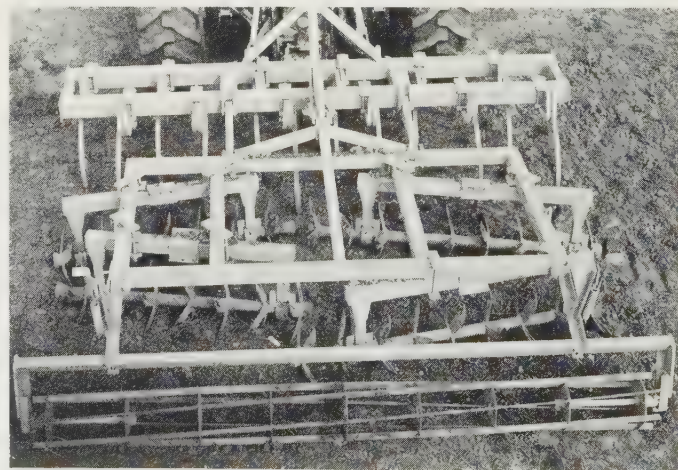
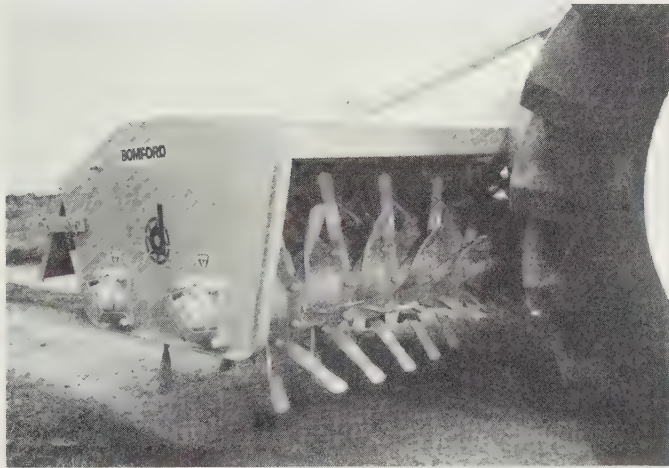


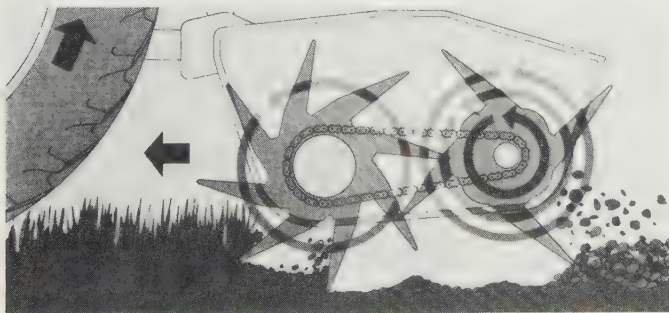
Fig. 6.13 Combination cultivator/harrow/crumbler for seedbed preparation, comprising two rows of spring-tine cultivator, two gangs of ground driven rotary harrow with adjustable gang angles, and crumbler roller. (Bomford)

Ground-drive tillage machines with gearing between rotors

Developments in multi-purpose implements include types with two rotors where the second is chain-driven by the first and designed to rotate at about $2\frac{1}{2}$ times the speed. On the twin-rotor 'Dynadrive' (Bomford), the two rotors are fitted with fairly long tines which intermesh to provide



(a)



(b)

Fig. 6.14 Twin-rotor mounted ground-drive seedbed preparation implement with second rotor driven by first at $2\frac{1}{2}$ times the speed.

(a) Raised to show front rotor tines arranged in spirals to provide smooth drive in hard soil for stubble breaking. Crumbler roller can be used at rear for seedbed preparation when needed.

(b) Diagrammatic section shows chain drive from first to second rotor. Intermeshing of tines assists self-cleaning in surface trash or damp conditions. (Bomford 'Dyna-Drive')

a self-cleaning effect. A major use objective is high-speed shallow cultivation in stubbles where there is sufficient initial firmness to permit the sharply forward-raked tines of the first rotor to enter the surface smoothly to provide the drive for the second, which has its tines rearwardly raked. In very hard dry conditions it may be necessary to make a second pass at an angle to the first. A high forward speed (10–12 km/h) is advantageous. For secondary cultivations in loose cloddy soil, fitting of a crumbler roller is often an advantage. For straw incorporation a screen of inclined spring tines may be used to restrain flying straw but permit fine soil to pass through and cover the straw as it escapes beneath the screen.

The SKH 'Crumbler' also employs chain-linked horizontal-axis rotors but uses a front row of fixed tines to achieve initial penetration. A typical combination has a leading row of tines attached to the main frame (choice of rigid and heavy-duty spring type with double-ended replaceable points); a ground-drive front horizontal-axis rotor with six rows of teeth arranged spirally; on one side a chain drive links this to a rear rotor by sprockets providing a $2\frac{1}{2}$:1 speed ratio. The rear rotor has rows of

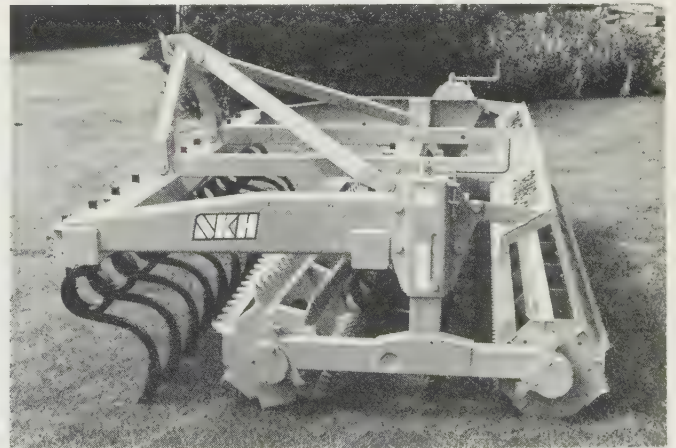


Fig. 6.15 Combination seedbed preparation implement with two rotors and two rows of fixed tines attached to the main frame. First row of tines stirs the soil and assists penetration of front rotor which has triangular teeth helically arranged. Second row of tines lies between the two rotors. The second rotor is chain driven by the first $2\frac{1}{2}$ times the speed; it throws the soil against adjustable deflector plates. Cranked handles regulate depth setting of the rotor-carrying subframe in relation to the main frame. (SKH)

smaller teeth, with an adjustable deflector above. Both rotors are carried on a sub-frame attached beneath the main frame by depth-adjustable slides. A second row of tines is attached to the main frame between the two rotors.

Power need is typically 25–40 hp per metre width at 6.4–11.3 km/h (4–7 mph). The wide range of adjustments makes the implement suitable for both stubble breaking and secondary seedbed preparation.

Rolls

The main objectives of rolling are to consolidate the soil, to crush clods and to smooth the surface. Consolidation is necessary on some soils to give plants a firm root-hold and to ensure continuity between the top soil and subsoil.

Spring rolling grass and cereals allows mowers and combine harvesters to run better at harvest. Care must be taken not to roll heavy land when it is wet down below, owing to the danger of the soil becoming ‘puddled’ or ‘poached’.

An important use of the roll on some farms is pressing stones into the soil in leys or pastures which are to be cut for hay or silage. A very heavy roll may be needed, and the work should be done in spring, while the soil is still moist.

If other factors remain constant the greater the weight of the roll, the greater are the degree of consolidation and the draught. The greater the diameter of a roll for a given weight, the lower are the draught and the consolidation. Rolls of small diameter sink into the soil farther than large ones, and the chief disadvantage of this is the tendency of the roll to push a wave of soil in front of it. This action may have disastrous effects on a growing crop. The most common diameters range from 508–762 mm (20 to 30 in), and the weight per unit length generally lies between 167–668 kg/m (1–4 cwt/ft), but may be 1336 kg/m (8 cwt/ft) where the roll is filled with concrete. Some plain (‘flat’) rolls may have their weight varied by water filling. Flat and ribbed (‘Cambridge’) types are most common in Britain, but much wider use of specialised clod-crushing rolls can be expected with the provision of rubber-tyred transport wheels.

The *Cambridge* or ‘ring’ roll has a number of ribbed cast iron segments mounted loose on an axle. The usual width of the rings is 75 mm (3 in), but 50 mm (2 in) rings



Fig. 6.16 (a) Hydraulically folded 10 m roller with serrated ring sections. Outer sections hinge vertically through 180° to position above inner sections. Outer and inner sections then hinge through 90° and are transported in vertical position. Centre section is raised for transport. (Vaderstad)

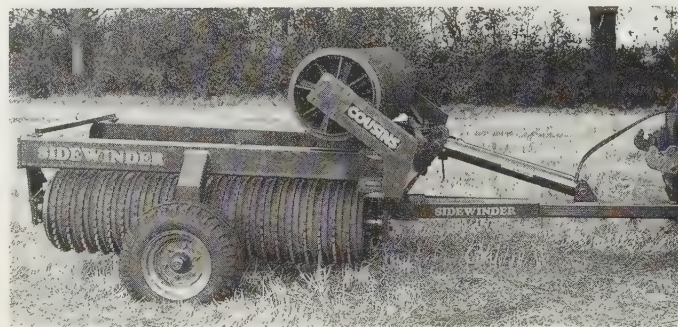


Fig. 6.16(b) Three-roll set with breaker rings providing working width 6.4 or 7.32 m (21 ft or 24 ft) and transport width as shown 2.5 or 2.8 m. To unfold for work, rear cross tie at top of frame is removed, and outer rolls when backed move apart at rear, each running in an arc on its single wheel. When fully open, middle roll is lowered by the single double-acting hydraulic ram to rear position behind the outer rolls, and the wheel-carrying frame members are pushed rearwards, putting all the weight of frame and wheels on the roll axles. The frames remain locked in line until the hydraulic ram procedure is reversed. (Cousins Side-winder TM)

are sometimes used. Each ring or section is raised at its centre to a narrow rim, so that the implement leaves a characteristic pattern of small ridges and grooves on the soil surface. The rings are free to turn independently on the axle, and are mounted so that there is a certain

amount of side-play to assist in keeping them free from soil. The bush of each ring, which is in contact with the axle, is chilled to make it resistant to wear. No attempt is made to lubricate this part, but the axle itself can rotate in lubricated bearings. The Cambridge roll is more effective as a clod-crusher and more generally useful than a flat roll. Many types of clod-crushing roll with spiked or serrated surfaces of various kinds are effective for fine spring seedbeds.

Now that transport problems have been solved by use of hydraulic folding and wheeled carrying frames, one of the serious disadvantages of such rolls has been eliminated (Fig. 6.16).

Fig. 6.17 Double-row reversible furrow press with five-furrow reversible mounted plough. When plough is raised at end of bout, the V drawbar attached to the plough releases the press drawbar before the turn. With the plough reversed after the

Furrow press

Modern furrow presses are designed mainly for simultaneous use when ploughing, often with a reversible plough and a press hitch which is dropped at each turn and picked up again on the next bout without stopping. Working widths range from 1 to 3 m. There are usually two widely spaced, sharply wedge-shaped cast iron press wheels per furrow, and width is tailored for the plough with which it is used. The towing arm rotates with the beam of a reversible plough, and the opposite of two towing hooks is picked up on the next bout (Fig. 6.17). Its use on soft light soils saves seedbed preparation time,

turn, the V drawbar is on the right-hand side, and with the plough lowered it automatically picks up the press drawbar at the opposite end of the press. (*Dowdeswell-Tigges*)



reduces soil moisture loss, minimises subsequent tractor wheel marks and permits earlier drilling. Incorporation of straw is often greatly assisted.

Crumbler rollers

Crumbler rollers have become widely used in combination implements, mainly at the rear but sometimes also at the front, as a convenient and very effective low-draught method of levelling and depth regulation. On some combined implements a crumbler is also used in the middle, between rows of fixed tines. Effects produced by different types vary widely: heavy large-diameter rollers with the narrow sections of heavy beams projecting from the cylinder at right angles to the direction of travel are powerful clod-crushers and can compress lower layers to a considerable depth without compacting the surface. At the other extreme, light small-diameter rollers with tubular bars fixed spirally round the cylinder can have a very superficial effect suitable for the final stage before drilling small seeds. When the compacting effect of a crumbler roller is not required or is harmful, it should be easy to take it off or raise it out of work so that its weight can assist tine penetration.

Rotary cultivators

Rotary cultivators with a single horizontal axis have now become accepted for both farm work and horticulture in Britain and many foreign countries. The rotor is generally driven from one end, to avoid an uncultivated strip in the centre. Sizes range from about 1 hp (0.75 kW) to over 100 hp (75 kW). Chief differences are in the types of blade or tine used and type and position of safety devices.

With tractor-driven machines a safety device is provided, either in the main drive or on the rotor shaft. This may consist of an adjustable slipping clutch, or a shock-absorber made of rubber driving pads. This simple resilient drive can provide all the protection that is necessary on smaller machines for ordinary agricultural or horticultural work.

Most rotary cultivators used in Britain formerly had L-shaped blades which are normally mounted with three right-hand and three left-hand blades per flange; but coarser work may be done by using only two right- and left-hand blades per flange (Fig. 6.18).

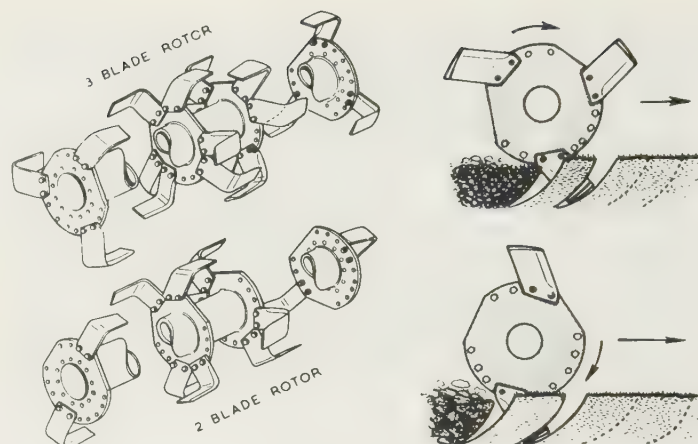


Fig. 6.18 Rotary cultivator rotors with L-blades, showing method of mounting and cutting action. (Howard Farmhand)

Other factors affecting the tilth produced are forward speed in relation to pto speed, and adjustment of the rear shield. The lower the gear chosen, the finer the tilth. Lowering the rear shield also tends to produce a finer tilth, due to the clods being thrown against it.

Modern tractor-driven rotary cultivators are usually fully mounted, the largest machines being fitted with a 'quick-hitch' to facilitate handling the heavy machine. Depth of work is normally controlled with the help of a wheel and/or skids.

Typical rotor speed range for a machine with a rotor 475 mm (18 in) in diameter is about 125 to 250 rpm. This gives a blade-speed of up to about 21 km/h (13 mph).



Fig. 6.19 Howard Rotalabour F1 rotor. The F1 rotor is suitable for a wide range of conditions including soils with a high stone content. The knife-tine is retained by a single bolt in a heavy-duty cast steel socket which in turn is welded to the rotor tube. The bolt is easily accessible with an air-powered spanner. The rotor is interchangeable with the Rotapoint type.



Fig. 6.20 Rotapoint Rotor. The Rotapoint tines are mounted tangentially to the rotor in a heavy-duty forged housing, providing a 'pick' action which will penetrate tough soil surfaces and hard, dry clods. The rotor can work directly into stubble to prepare a seed-bed for oil-seed rape, or after ploughing as a secondary cultivation for cereals. Power requirement is low. Fastening by single nut and bolt is accessible to air-powered spanner.

Normal width of cut ranges from about 1.2–2.4 m (4–8 ft), but machines over 3 m (10 ft) wide are available for use with high-powered tractors. Normal depth of work is up to about 250 mm (10 in).

Besides the now widely used rotary cultivators with a transverse shaft carrying various types of blades designed to work to a depth of about 230 mm (9 in) when necessary, there are also wider implements designed mainly for shallow working, and implements with a rotor having radially mounted spikes or blades.

Some of the most useful powered cultivators of the horizontal rotary axis type also employ undriven tines and often a rotary crumbler in the form of a combined seedbed-preparation machine.

Power harrows

Harrows of conventional zig-zag type often produce a disappointingly slight effect in one journey across a field, and at the same time they provide such a light load that a medium-powered tractor is employed at only a small fraction of its full capacity, even with a wide implement. Pto-driven tractor-mounted reciprocating and rotary harrows are therefore of considerable importance in that a light machine can produce an effect equal to that of several ordinary harrowings and rollings. Like the rotary cultivator, the power harrow differs fundamentally from



Fig. 6.21 The 4 m power harrow, largest of its range, uses 356 mm (14 in) tines to work the soil to 254 mm (10 in) deep. The harrow is close-coupled to a toothed packer-roller with scraper to prepare a good one-pass seedbed. Power need for high-speed work is met by M-F 3080 fitted with Colmant Cuvelier 'KITCO' rubber wrap-round half-tracks. (Massey-Ferguson)

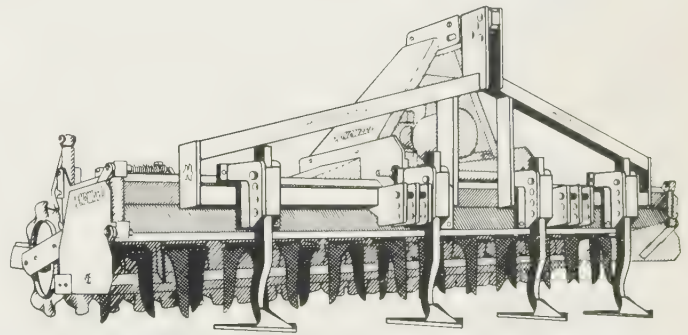


Fig. 6.22 Power Harrow shown with a compact grubber. (Howard)

The VGC grubber is a long-shank broad V-bladed tine capable of 130–200 mm (6–8 in) deep work immediately ahead of either rotary cultivators or power harrows. The soil 'boils' ahead of the power machine, and a toothed packer-roller at the rear consolidates and helps to produce friable soil at sowing depth for most crops.

the many harrows which have been developed from implements originally used for animal draught.

Reciprocating harrows have an arduous task, in that reciprocating motion always involves vibration, and that

the bearings have to work very close to the soil. It proved difficult in the past to obtain a reasonably long life from such equipment; but progress in the design of bearings and in developing really robust equipment resulted in a reasonable degree of reliability.

A typical two-bar multi-purpose implement has a maximum working depth of 200 mm (8 in) and operates with a short stroke at high frequency. A crumbler roller may be attached to firm the top of a seedbed.

A typical power driven rotary harrow has an even number of vertical rotors, arranged in a single line and with adjacent rotors contra-rotating. Tine length generally ranges from 230–306 mm (9–12 in). Each rotor carries two tines and for normal duties the tine bars of adjacent rotors are set at right angles to one another.

Fig. 6.23 Features of modern high-specification power harrow design available in 3, 3.5 and 4 metre widths. (*Dowdeswell Power Harrow*)

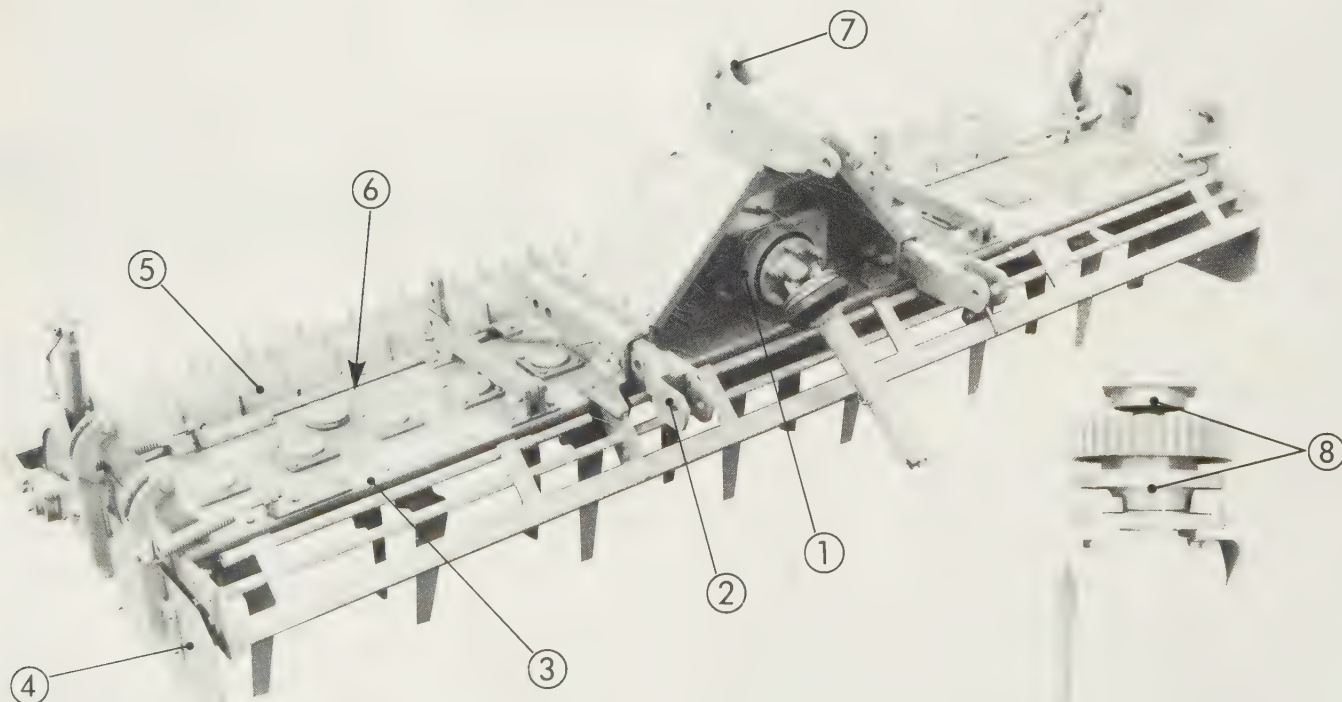
1 Sturdy "Speedset" gearbox with choice of four standard rotor speeds and the option of two additional intermediate speeds; 2 Floating or fixed lower link connections at 2 or 3;

Length of tines or knives and width of each rotor tend to be related to the tractor power for which the machine is designed. The greater the dimensions of each rotor, the higher the power normally needed for a given overall width of work. At the top end of the scale, a tractor of about 200 hp with dual-speed ptos and reversible knife tines 356 mm (14 in) long can be expected to operate at a working depth up to about 254 mm (10 in).

Rotor speeds may be adjustable by change-speed gears on the implement. For normal seedbed preparation the lowest working speed to secure a satisfactory result is recommended.

Vertical-axis power harrows may be designed either for use with rotating tines or knives. The tine type relies rather more than the knife type on other components to

3 Deep-section 6 mm plate hull; 4 Spring loaded side guards; 5 Optional heavy-duty packer roller with adjustable scrapers or lighter alternative options; 6 Standard rear levelling bar; 7 Standard rear hitch; 8 Rotor assembly with heavy-duty well spaced bearings and rotor drive gears running in a semi-fluid grease.



provide some resistance to sideways movement of clods and so prevent their avoiding the crumbling action of the rotors. Restraining devices may include the rear faces of front levelling bars: clod combs and rear crumbler rollers. When such devices are located close to the periphery of the rotors, the escape of large stones has to be provided for in the design. Breakages and wear caused by stones can make choice of non-power-driven implements preferable on some soils.

All power-driven soil-working implements for deep working need reliable devices for protection against overloading. One automatic shear-pin resetting device has two cartridges of five shear-pins, each of which provides for up to five breaks (Lely 'Automat').

The short length of power-driven harrows makes it practicable to hitch another implement such as a light seed drill directly behind the harrow. For this purpose a specially designed three-point linkage assembly with suitable stabilising bars and chains may be used. For machines wider than 3 m problems of road transport may need to be considered.

Figure 6.23 illustrates main features of a machine claimed to be the first power harrow of vertical axis rotor type designed and manufactured in Britain. It is CAD/CAM designed and manufactured by a world leader of tillage machinery manufacture; the 3 model range with 3.0, 3.5 and 4.0 m working widths has an attractive specification. Emphasis is on strength and quality of the main drives and rotors, and the rugged hull of 6 mm plate is typical of the company's standards. The optional packer roller and availability of heavy duty 12 in blades will be needed to compete in an increasingly competitive sector of the market. An optional end transport kit will be needed for the 4 metre model by most users.

Implements for row-crop cultivations

The drilling of seeds in rows enables cultivations to be carried out during the growth of the crop. Jethro Tull (1674–1740) did much by writing and by example to popularise the use of drills and horse hoes, and he emphasised the benefits conferred on the crop by repeated hoeings. His *Horse Hoeing Husbandry*, published in 1733, was largely responsible for bringing about a general change from broadcasting to drilling. More recent comparisons with herbicide use show hoeing in excess of the amount required to kill weeds is often wasted effort

and detrimental to the crop. The main object of inter-cultivations is the destruction of annual weeds, and few British farmers now carry out more hoeings than the minimum required to achieve this object.

Ridgers

Ridging ploughs are chiefly used in the cultivation of root crops, and especially of potatoes. Owing to general use of potato planters they are used less than formerly for drawing out ridges in which the potatoes are planted, or for 'splitting' the ridges. They are used before stone windrowing and for 'moulding up' when cultivations are complete. In some districts, notably the north of England, roots are often grown on the ridge.

Ridging outfits include: rear-attached tool-bar fitted with ridging bodies, tool-bar attached amidships or in front. The ridging bodies used for front coverers are usually of a short, shallow-working type, which does not press the soil into the ridge formed, so avoiding formation of clods. Ridging work can also be done by concave discs, suitably angled (often used on potato planters) or by a power-driven rotary ridger.

Grubbers for row crops

The philosophy of inter cultivation of row crops has been revolutionised by practices such as stone and clod windrowing, and by the success of selective herbicides. With potatoes, the objective of many leading growers is to plant in completely stone and clod-free ridges and then to leave the soil alone until the ridge is lifted by the harvester. However, this objective is impossible to achieve on some soils and difficult on others; and in practice many crops are worked by a grubber and/or ridger at least once between planting and harvest. The most favoured types of grubber units float independently on a rear toolbar. Each carries several small slightly curved or straight tines with easy adjustment for both depth and line.

Hoeing tool-bars

Weed control in sugar beet and similar crops has become more a question of the best choice and use of herbicides



Fig. 6.24 A six-row cultivator/hoe for front or rear mounting, using front-mounted hoes in sugar beet. The heavy lever-action units fitted with side-shields can be self-steered for rear hoeing if suitable marker tines are fitted and used when drilling, and two centre-ribbed wheels used to follow in the grooves created. (*Standen 'Multivator'*)

than of problems concerned with the use of hoes. Hoes are still used and often to good economic effect; but it is usually when for some reason the herbicide programme does not achieve normal good results that there is the kind of pressure on hoeing that prevailed when weed seeds were allowed to compete on level terms with the sown crop. There usually remains a need to carry out a fairly early close hoeing with equipment that prevents the soil being pushed on to the crop, and a high-speed operation before the crop leaves meet across the rows.

Tractor hoeing outfits include the following main types:

Rear-attached tool-bars often independently steered by hand. The low forward speed at which accurate steering can be achieved and the constant effort required from the operator make such two-man outfits unattractive. A type with *automatic ribbed wheel or fin steerage*, which follows grooves cut in the soil when drilling the crop, has a much higher labour productivity. With large side shields to protect the crop this type can be used at high forward speeds in suitable soils, and as a 12-row one-man unit it can be competitive with other methods of weed control.

Mid-mounted hoes, which respond immediately to steering of the tractor itself can be satisfactory. Hoe blades must be used to eliminate the rear wheel tracks.



Fig. 6.25 Tool-carrier suitable for 12-row hoeing in crops such as sugar beet, seen here with crumbler roller/drill/sprayer combination. (*Fendt*)

Tool-bars mounted in front of the front wheels. With some tractors the hoes are too far away for the driver to have a really good view of them.

There are, in addition, the self-propelled tool-carriers, which can do very accurate work, and may be satisfactorily used where there is a sufficient amount of drilling and hoeing to justify purchase of such an outfit.

There are important differences in construction between different machines in all the above main groups. Thus, some have the hoes mounted on a parallel-linkage framework, while others have them independently mounted at the ends of levers, like the coulter of a drill. Some have springs to press the hoes into the ground, while others employ weight.

Certain essential requirements apply equally to all kinds of drilling and hoeing outfits. The tools must be easily put on and removed from the tractor. The hoes must be easily visible from the driving seat. They should float easily in a vertical direction, to accommodate themselves to uneven land, but must be rigid in a sideways direction, so that they do not wobble, and so that they respond immediately to steering.

Thinning machines

Simple thinning machines make a large number of small cuts at regular intervals along the row. The cuts are

normally very small in relation to the desired final spacing. Such machines are generally of two main types: the rotary-head and the oscillating type. The rotary-head type tends to be preferable for dealing with adverse conditions, especially weedy crops. Such machines were rapidly made obsolete by developments in seed drills and herbicides, especially for sugar beet and brassica crops.

When simple thinners are employed, the thinning is entirely random, and the machine will therefore remove strong and weak plants indiscriminately. It may create excessively wide gaps where the braird is thin. It is, therefore, essential to have a good uniform braird where a mechanical thinner is to be employed; and in order to avoid the danger of using the machine in unsuitable crops it is advisable to make thorough counts of the plant stand before beginning work.

Whatever the type of thinner, depth of cut can only be decided in the field. The object must be a clean cut, with a minimum of disturbance of adjacent plants. Forward speed should not usually be higher than about 3 mph (4.8 km/h), because higher speeds tend to result in too much bursting of the surface soil.

Automatic selective plant-thinning

With crops such as sugar beet, the aim of growers is a stand of about 30 000 plants/acre (74 000/ha). This requires row widths and spacings within the row as follows:

Row width		Spacing in row (approx.)	
(mm)	(in)	(mm)	(in)
460	18	300	12
510	20	260	10½
560	22	230	9

Slightly lower plant numbers may be better in areas where very large tops are grown.

Minor irregularities of spacing have little effect on yield; so because germination of every seed drilled cannot be relied on, and some plants may die in adverse conditions, efforts to produce the required plant number by 'drilling to a stand' are based on a smaller spacing in the row than indicated by these figures. For example, a spacing of 180 mm (7 in) or less may be aimed at. It was once thought certain that automatic electronically-controlled thinners would have an assured place in growing root crops in Britain, the automatic controls being so arranged that existing gaps above a maximum desired size would not be enlarged. Practical machines were developed, sold and used by a few farmers, but they were not sufficiently free from operational difficulties. On most farms improvements in seedbed preparation, drills, and the use of herbicides together overtook development work on thinners to such an extent that 'drilling to a stand' rapidly became the most usual aim. The use of mechanical thinners of any kind soon became only an emergency operation. There is a great deal of basic information on thinning contained in reports of experiments, should the need for it again arise.

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Equipment for Sowing and Planting

The sowing of seed is one of the many agricultural operations concerning which there is a vast store of general information, gained from experience stretching from biblical times, and relatively few hard scientific facts, in spite of almost ceaseless experimentation both in Britain and abroad.

The main difficulty in arriving at hard facts is that there are so many variables which in nature cannot be controlled. Even if, by taking great care, the experimenter succeeds in controlling the quantity of seed sown per unit area, the spacing of drill rows and the depth of sowing, he can hardly hope to control the weather, the soil behaviour under various climatic conditions or the incidence of certain types of diseases.

For such reasons, the best guidance on sowing requirements that can be given is usually in fairly general terms; and every now and again, faith in the general recommendation is shaken by successful introduction of a new practice which is quite different. This may apply to seed rate, row width, depth of drilling or even adoption of broadcasting rather than drilling. For crops such as cereals, there is a wide range of seed rates and plant populations over which yield varies little. With such crops, seed rate needs to be above a certain minimum, this minimum rate being necessary to ensure the absence of any large gaps in the crop. Experiments on spaced drilling of cereals show that where potential yield is high, yields can be increased by spaced drilling in 100 mm (4 in) rows compared with use of 175 mm (7 in) rows. A minimum seed rate of about 135 kg/ha (120 lb/acre) is needed for barley, and spacing in the row is about 25 mm (1 in). The technique could have special importance for multiplication of seed crops. For many root and vegetable crops, however, there is a fairly narrow range of plant populations that will give maximum yields under a particular combination of soil and fertility factors. As a general rule,

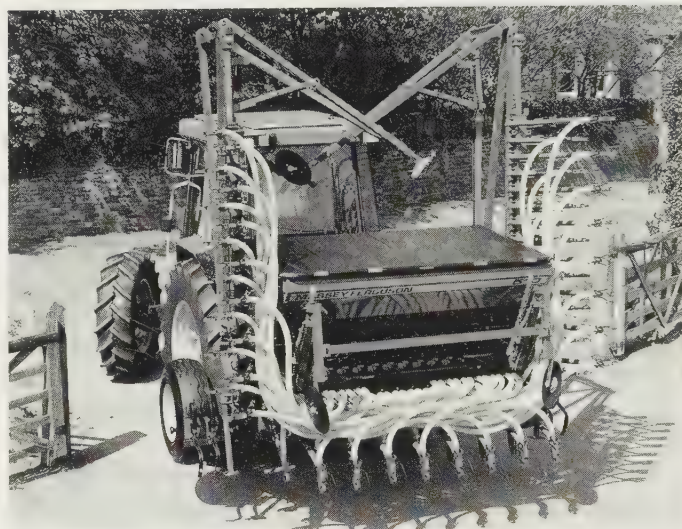


Fig. 7.1 The increasing popularity of pneumatic seed drills is partly due to the ease with which standard components can be used for ranges of mounted drills with sowing widths from 4 to 8 m. Hydraulically folded coulter bars and markers enable drills up to 8 m wide to be folded to a transport width of 3 m immediately field work is finished. (*Massey-Ferguson 510*)

the number of plants per unit area for maximum yield increases with increasing fertility.

Uniformity of spacing is also important from the viewpoint of securing effective mechanical harvesting in carrots and sugar beet: mechanical harvesters work much better where the roots are of uniform size.

General design of drills

General-purpose drills may be used for sowing all kinds of seeds from the size of beans to that of clover, at

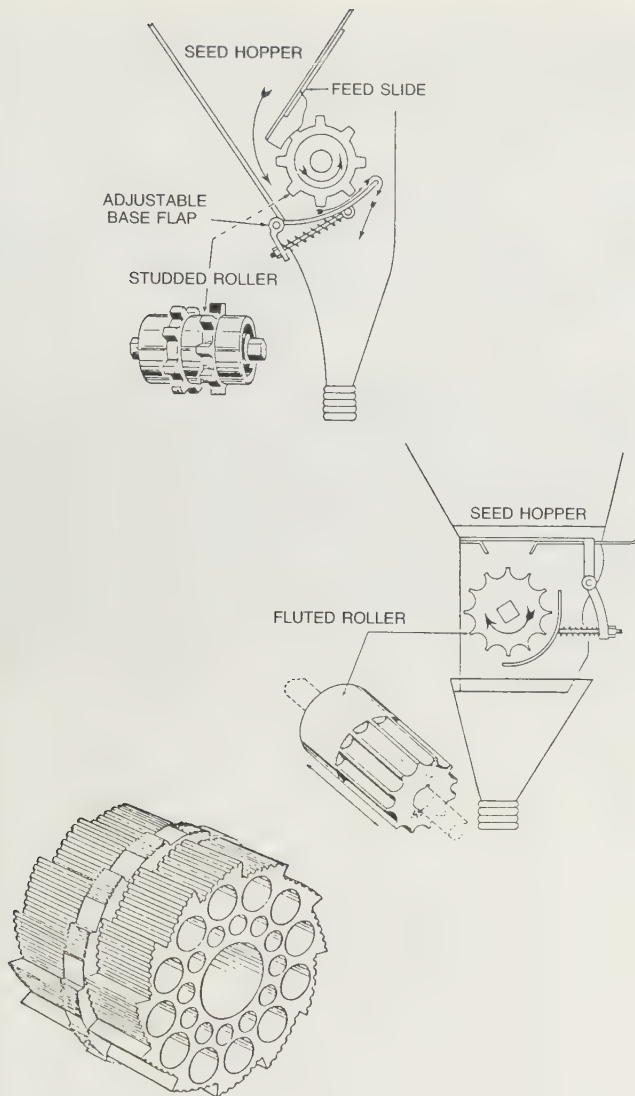


Fig. 7.2 Drill feed mechanisms.
 Above: Studded roller feed.
 Centre: External (fluted roller) force feed.
 Below: Flexible fluted roller force feed. (Parmiter)

various seed rates and depths, and in rows at various distances apart. Most are 'full-width' machines with a braced frame and a seed box extending across its width. The seed is delivered from this box by feed mechanisms driven by gearing from one or both land wheels. There is a separate metering device for each row. A clutch is

included for putting the feed mechanism in and out of gear. The seed passes down seed tubes to the coulters, which cut grooves in the soil. The seed rate is adjusted by alterations of the gearing or of the feed mechanism; and the spacing between rows and the depth of sowing are adjusted by the setting of the coulters. The more common types of feed mechanism and coulter are described below.

Most general-purpose drills have a metering mechanism located immediately above each coulter, but increasing use is also made of drills with metering devices centrally grouped beneath a large bulk hopper, with delivery to the coulters by air streams conveyed along individual tubes.

Feed mechanisms for full-width drills

External force feed

A fluted roller was used as the feed mechanism on some of the earliest English drills. The mechanism of the modern external force-feed drill consists essentially of a fluted roller which rotates just below the seed box and draws seed from the bottom of the box into hoppers at the tops of the seed tubes. The seed box is a single compartment, and the fluted rollers rotate in feed runs attached to the bottom of it. In a simple type the rollers are fluted over only half their length, and can be moved laterally so that either the plain or the fluted portion, or a part of each, is in contact with the seed. This provides a simple regulation of the seed rate; for no seed is delivered by the smooth part of the roller. On some machines the rollers are connected to the drive shaft by individual dog clutches, and coulters may be shut off as required by disengaging these clutches. The use of spring-loaded baffle plates in the feed runs causes less damage to large seeds and permits adjustments for drilling various types of seed and for varying the seed rate. A type of feed roller with spiral flutes is self-cleaning and can provide a continuous flow of seed which in practice results in a very even spacing of cereals and small seeds (e.g. Falcon). On a typical drill the baffle plates or feed gates can be set in any of three positions: quarter-open for small seeds, half-open for medium seeds, e.g. cereals, and three-quarters-open for large seeds.

Developments include the use of large-diameter rollers with the corrugations formed in flexible urethane. For

small seeds such as grass or rape only the centre section of the roller is used, the rest being shut off by adapters placed in position above the rollers (e.g. Parmiter).

Internal double-run force feed

The internal force-feed mechanism was developed in the United States, and is especially efficient for sowing cereals. The feed mechanism consists of a shaft carrying a series of flanged discs, the insides of the flanges being slightly corrugated. Each feed disc is housed in a casting which fits in the bottom of the seed box. As the wheels rotate, the seed is drawn by the corrugations past baffles to a point outside the box, where it falls into the seed tubes. On one side of the flanges, both the serrations and the clearance between them and the baffle are smaller than on the other side. Either side may be used at will by adjusting the position of a hinged flap in the hopper, which covers either the coarse or the fine side of the feed run. When sowing oats the coarse side is required, while for wheat the fine side generally gives a sufficiently high seed rate.

This type of mechanism has the advantages of all force-feed drills, and gives a more continuous flow of seed than the external-feed type. Its main disadvantage is that it is less adaptable than the external force-feed type, being really suitable for sowing few crops apart from cereals.

Combine drilling is discussed in Chapter 8.

Studded roller feed

In many European countries, a common type of feed consists of a studded roller (Fig. 7.2). This has many advantages, one of the chief of which is a wide adaptability. Many Continental drills imported into Britain use a studded-roller feed, usually in association with a multi-speed gearbox for variation of sowing rate.

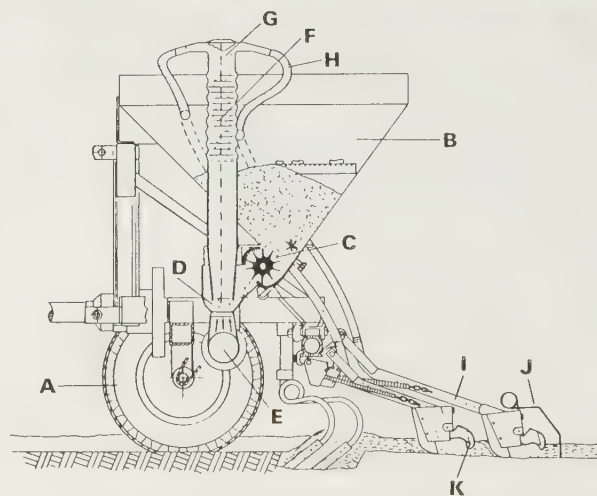
'Pneumatic' or 'jet' drills

The basic feed mechanisms on many general-purpose drills that use air for distribution consist of a battery of fluted nylon rollers, driven via variable gearing from the land wheels, and with one such unit for each coulter. The mechanically metered seed is then conveyed along pipes to the coulters by means of an air-stream from a pto-driven fan.

Another principle is widely employed in the drills of an important German manufacturer (Accord, see Fig. 7.3). In this type the whole of the metering for drills up to 4 m wide, or for each of a pair of units in drills up to 8 m wide, is



(a)



(b)

Fig. 7.3 (a) A 4 m pneumatic seed drill with 32 shoe-type coulters. The outer four coulters on each side can be folded upwards for transport or for use behind a 3 m power harrow. (Ferrag/Accord)

(b) Grain and air flow in Accord seed drill.

Land wheel A drives deeply fluted metering barrel wheel C, which has rubber-lipped seal immediately below and nylon brush above it. Seeds drop into venturi of injector tube D. Regulated air flow from fan E carries seed through diffuser tube F to mushroom-shaped distributor G, and on via flexible seed tubes H to coulters I. Coverers J close coulter furrows. Hinged stops K prevent soil blocking delivery opening when machine is lowered or backed. (Copyright diagram by courtesy of Power Farming)

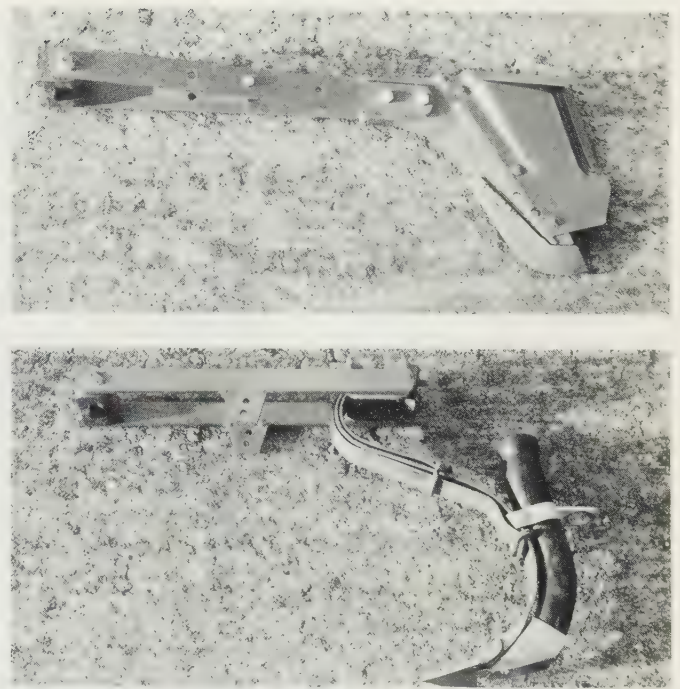
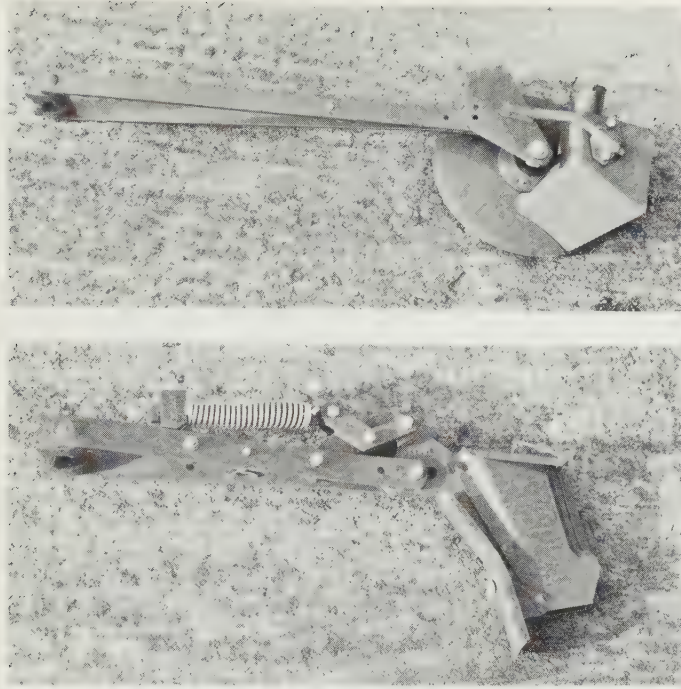


Fig. 7.4 Conventional drill coulter assemblies (*Massey-Ferguson*) Above left: Disc, above right: Suffolk, below left: Hoe, below right: Tine.

carried out by a single metering barrel. The stream of air containing seeds passes through a vertical diffuser tube having corrugated walls. At the top it is split up into equal parts by a carefully engineered circular distributor of a mushroom shape which feeds the flexible delivery tubes leading from its periphery to the coulters. Sowing rate, which is infinitely variable, is set by adjusting the effective length of the metering barrel by a screw which sets the position of a sliding blanking-off plate. For small seeds, release of a single catch blanks off the deep flutes in the feed roller. The amount of air needed for accurate delivery depends on seed size and seed rate; pto drive speed and fan throttle setting need to be checked during calibration.

Cultivator air-delivery drills

A type of air-delivery drill hitherto typical of types used more in North America and Australia than in Britain is based on a heavy-duty spring-loaded C-tine cultivator arranged in a four-row stagger and fitted as standard with

180 mm (7 in) A-coulters designed to cut the whole working width and deliver a broad band of seed. (Fig. 7.7). Other coulter types are available for special needs. In work, the trailed hopper with metering unit(s) runs on its own wheels, and the cultivator is independently depth-regulated by tandem wheels on 'walking' beam axles to maintain an even sowing depth over fairly rough surfaces. The general design features make this type of drill suitable for use on large-scale medium or heavy-land farms in working widths of 6 to 12 m, where four-wheel-drive tractors of 90 to 200 hp are available.

Drill coulters

The Suffolk or 'shoe' coulter was formerly the most popular type in Britain, but the single-disc type is now widely used. In the Suffolk, a renewable chilled iron shoe cuts a groove in the soil and the seed is delivered by the seed tube into the groove. In good conditions this coulter works

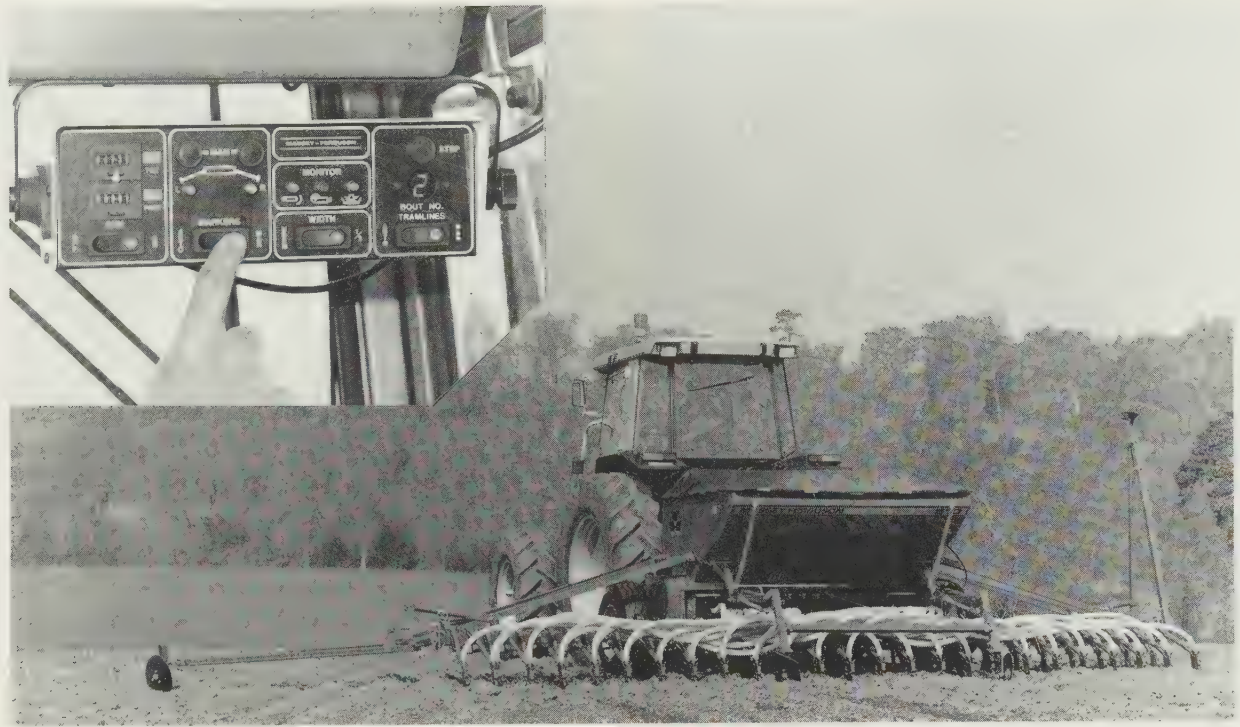


Fig. 7.5 8 m pneumatic drill with electronic package providing for tramline system with markers and other controls which can be operated automatically or manually by push-button. The console shown inset can remain permanently fitted in the

tractor cab. It monitors feed shafts, air delivery system and hopper seed level. Area covered in acres or hectares is provided in two displays, one for part area with reset button, and the other for cumulative total. (Massey-Ferguson 510)

Fig. 7.6 General arrangement of patented air flow and seed delivery system on Massey Ferguson 510 pneumatic seed drill. The 540 rpm pto drives a centrifugal fan A delivering $34 \text{ m}^3/\text{min}$ ($1200 \text{ ft}^3/\text{min}$) into a wide plenum chamber with multiple evenly spaced exits to specially designed venturis B beneath corresponding spiral fluted seed metering rollers C below the seed hopper D. The metered seed flow is picked up by each venturi and carried on to points nearer the drill where a row of flow dividers splits each air stream into two, which each deliver the seed along flexible tubes F to individual Suffolk type coulters G. The spiral roller feed units are of MARKSMAN™ type, identical with units developed for the MF500 drill. Tests have shown that there is very little variation in the amounts of seed delivered to the individual coulters. (Diagram courtesy of Power Farming based on Massey-Ferguson original drawing)

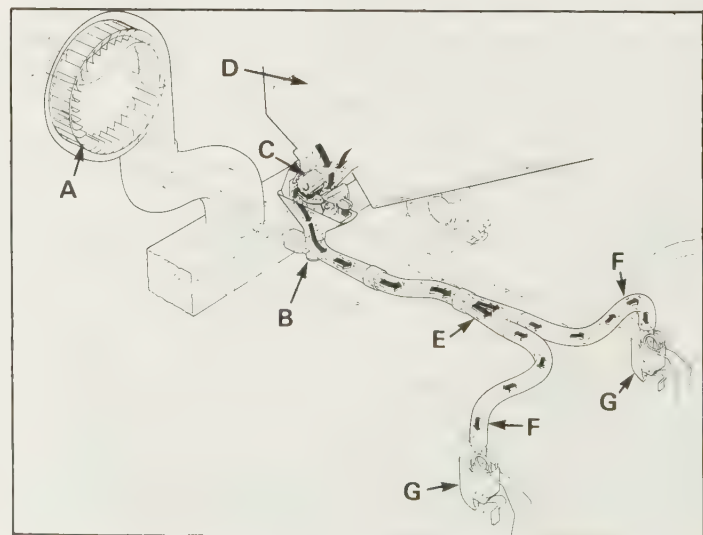




Fig. 7.7 9 metre pneumatic seed delivery cultivator drill designed for high-speed combined cultivation and sowing in UK conditions. An adjustable spring-steel comb assists seed cover when working conditions require it. (*Reco-Wil-Rich*)

satisfactorily, the soil falling back on the seed and covering it well.

In the single-disc coulters a saucer-shaped hardened steel disc cuts the furrow, and the seed is delivered to a 'boot' attached to the convex side of the disc, just below and behind its centre. The great advantage of the disc type is that it will work satisfactorily in all kinds of unfavourable conditions. Where the ground is hard a fair penetration can be secured; where there is rubbish the discs will cut through it and not collect it; where the tilth is poor, the discs effect an improvement by their pulverising action; and where it is sticky, discs will keep clean better than other types of coulters. The single-disc coulters thus has many attractive features. Its disadvantages are the initial expense, the fact that it does not place all the seed at the same depth and the need for either constant attention to lubrication of the bearings or provision of high-class sealed bearings. The effects produced by single-disc coulters depend partly on the disc profile and the design of the seed boot. Development work has resulted in improved uniformity of seed depth and ability to work well at row spacings down to 120 mm ($4\frac{3}{4}$ in.).

The hoe coulters resembles a cultivator share, with a half-round or V section. The point of hardened steel is usually reversible. Its chief advantage is its simplicity and ease of penetration, but its depth of work is not uniform and it can cause trouble when working in rubbish.

'Wing' coulters are available for sowing cereals on drills originating in Finland. The seed is spread in a band that is usually about 5 cm wide, and this can result in strong development of individual plants. Similar effects can be produced in light friable soils by use of wide shoe coulters fitted with a hinged band-sowing attachment (e.g. Amazone). With all band-sowing systems initial cost,

draught and expense on replacement parts, are factors to be considered in making overall comparisons.

The coulters are usually attached to levers which hinge on a cross-bar at the front of the drill. The normal method of control on modern drills is by use of the tractor's external hydraulic power; but the exact means of control are varied. Ability to regulate sowing depth accurately in hard soils or when working in trash was studied closely by manufacturers in a period when 'direct drilling' was widely practised, and some of the positive control features developed for such adverse working conditions have subsequently proved useful for more general needs.

The Moore Uni-Drill (Figs 7.8 and 7.9) is based on a unique arrangement of coulters and heavy weight distribution which is best described with the help of illustrations and lengthy captions. Its development began when extensive use of overall weedkilling by non-selective herbicides for cereal growing was widely practised; but the current production has blossomed into an all-purpose drilling machine capable of very good high-speed work in a wide range of soils and crops world-wide. A major control

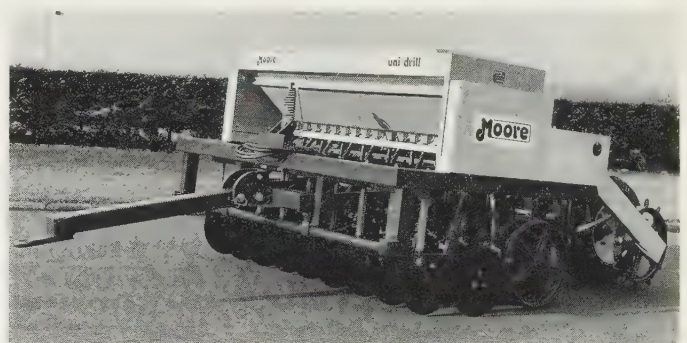


Fig. 7.8 Moore Uni-Drill General Arrangement

The drill comprises three major parts: an upper frame carrying the seed-box, metering mechanisms, seed tubes and front lower horizontal bar to which specially designed coulters drag arms are attached; a drawbar hinge-connected at the rear end to the drill frame near its fore-and-aft centre of gravity; and a single longitudinal centre located depth adjustment screw which operates by opening or closing the angle between the upper drill frame and the drawbar (see Figs 7.9(a) and (b)). A pair of hydraulically controlled land wheels at the rear lift the machine out of work at the headlands and for transport. A spiked land wheel drives the seed metering mechanism, and stationary calibration of seed rate by the studded roller feed mechanism is facilitated by use of the feed drive covers as seed collecting trays. (*Moore Uni-Drill*)

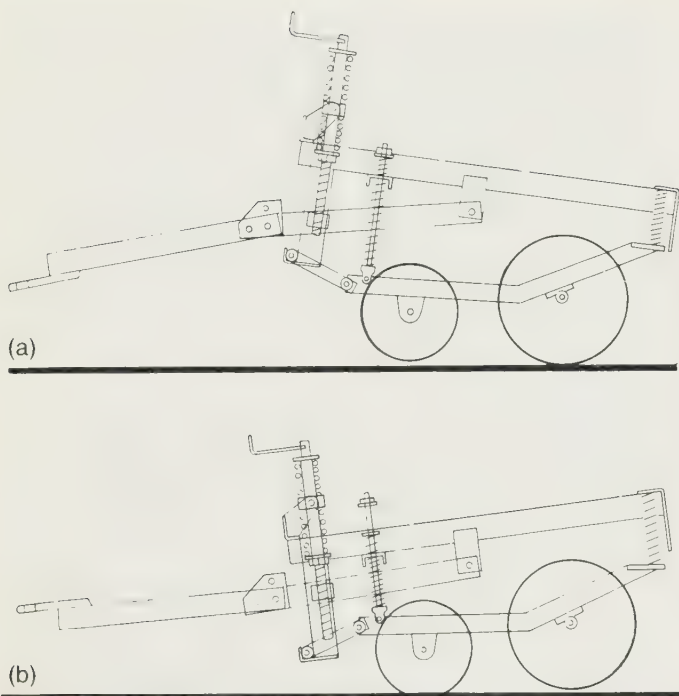


Fig. 7.9 Depth regulation. Figs (a) and (b) indicate settings for minimum and maximum penetration by operation of the single major depth control screw. Working position lies between the extremes illustrated, the key being transfer of drill weight from or to the coulters by the press wheels at the rear. At the correct intermediate frame setting for the site, individual spring pressure applied between the frame and the drag-arms ensures a uniform drilling depth except in extreme conditions such as when large flat stones in dry soil cause the discs to rise against the spring pressure on the individual coulters concerned.

feature is single screw weight transfer from press rollers at the rear to coulters at the front and vice versa.

A common coulters spacing for cereal crops in Britain is about 180 mm (7 in). This is a compromise arrived at as a result of a few experiments and long experience. Experiments have, however, shown that there is advantage in a closer spacing on light soils, especially for spring-sown crops such as barley. Many modern drills provide for spacings down to 100–125 mm (4–5 in). Such narrow spacing, generally achieved with small shoe-type coulters, results in a higher capital cost and higher maintenance, not necessarily justified on heavy land.

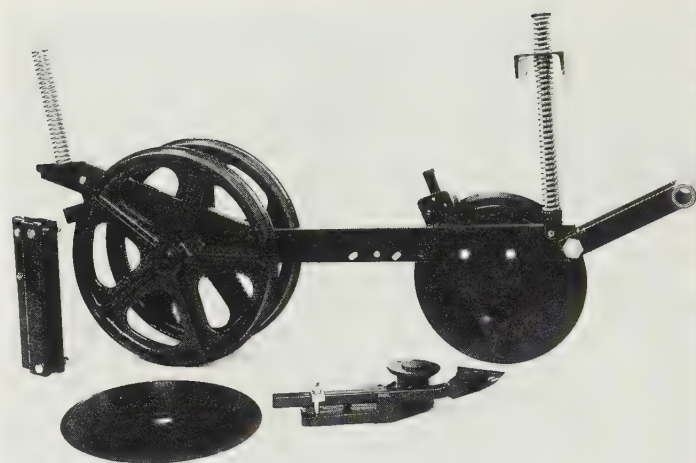


Fig. 7.9(c) Principal soil-working parts. (*Uni-Drill*) The Uni-Drill employs a unique arrangement of two-row drag-arms carrying two staggered lines of flat-disc coulters, one on each side of the drag-arm, and inclined inwards at an angle of 5°. Each disc bracket carries an independently depth-adjustable pointed seed coulter which is normally set to run in the furrow cut by the disc. The illustration shows a normal seed coulter setting in the far-side front row: disc, seed coulter and bracket of the near-side second row coulter assembly have been removed, and when fitted will have the seed coulter assembled on the far side of the inwardly inclined disc. The two heavy press wheels at the rear run precisely above the centres of the two rows of seed.

Many drills of Continental origin have a fairly complex series of spur gear trains, and a system of selection by means of movable idlers. Some modern drills use oil-bath spur gearboxes which provide a large number of speeds: others use a 'variator' drive to provide an infinitely variable adjustment of sowing rate.

A simple counter driven from the main drive shaft registers the area seeded and provides a useful check on seed rate calibration. Modern drills should be equipped with a hand-operated crank and measuring tray for easy stationary calibration.

Tramlining

The term 'tramlining' is applied to the practice of leaving unsown strips in cereal or similar crops at the intervals

required to facilitate accurate and speedy application of sprays and fertilisers to the growing crop. The most common requirement is to arrange for distributor and sprayer bout width to be three times that of the drill, and so to provide a mechanism positively shutting off the necessary drill coulters at every third bout. With narrow-spacing drills it is necessary to shut off two coulters for each wheel-track, and a common wheel-track spacing is about 1800 mm. The mechanism is set to operate first on the second bout. A common method of providing automatic operation is by a cam that is partially rotated each time the drill is lifted out of work. An override control is needed to correct for any necessity to lift the drill before a bout has been completed. In a typical mechanism, cut-off slides are held out of action by a hydraulic ram when not tramlining, and are kept in position by springs on the tramlining bout. A visual indicator shows which bout of the three-pass system is in progress.

Electronic tramlining: Modern multi-purpose drills are normally offered with electronic tramlining equipment having a control box operated by pressure switches from the tractor cab. The preferred method is to stop rotation of the selected feed runs by means of solenoids and clutches. Provision of a selection of tramline bout frequencies (to permit adjustment to change of need) is usually accompanied by a visual display and an audible warning of failure to follow the correct sequence.



Fig. 7.10 Single-pass 4 m cultivation and drilling by high-powered tractor fitted with LGP tyres operating front-mounted spring-tine cultivator, rear-mounted power harrow and crumbler roller, with Nordsten CLP drill and spring-tine covering. (Howard G.B.)

Side benefits of good tramlining practices include minimising green grains in the cereal sample, and a small saving of seed. Compensatory growth usually results in an insignificant loss of grain yield. The full benefits are most likely to be obtained when 'full-width' distributors are used, and good weed control is achieved.

Types of drill

Semi-mounted tractor drills

Many tractor drills are carried on and driven by their own two wheels, but are connected to the hydraulically operated three-link system of the towing tractor. The hitch is so devised that raising the drill coulters and shutting off the seed delivery is simply effected by operation of the tractor's hydraulic lift control lever. This eliminates the uncertainty and slow action typical of mechanical drill lifts. The lift can, of course, be operated without the necessity of moving forwards. Headlands can be narrow, and the drilling can be started or stopped to a more accurate line than with trailed mechanically lifted drills.

Tractor-mounted drills

Several firms now manufacture their lighter types of drill for direct mounting on the tractor's three-link hydraulic lift system. With such drills the wheels are used to drive the mechanism, and putting the drill out of gear is simply effected by lifting the whole machine bodily off the ground. As soon as the drive wheels are clear of the ground the drive to the feed mechanism automatically stops. It seems likely that this method of mounting will be applied to most of the light drills of the future, while the semi-mounted method is likely to be increasingly employed for the heavier corn and combine drills.

Equipment for 'direct' drilling

When the benefits of 'direct' drilling (with no other cultivation following previous crop) were first widely appreciated, a few manufacturers successfully developed heavy grain and combine drills which employed 'triple-disc' coulters comprising a single plain disc to cut a slit, followed by two inclined plain discs to form a V-groove in which the seed was placed. Experience gradually showed the

benefits of more flexibility allowing for shallow cultivation before or during drilling when needed: methods of sowing-depth control which can be effective in soft or hard soils; and coulters with fewer bearings and wearing parts. Modern drill designs reflect the changed needs of users, and provide for more efficient use to be made by hydraulic power to secure penetration without use of excessive dead weight. At the same time, improved coulter designs make it easy to carry out an appreciable amount of tillage when needed. Coulter designs include extra large diameter (e.g. 356 mm (14 in)) single concave discs capable of cutting through trash, yet with a profile narrow enough to permit close spacing, and with a boot and scraper capable of use in sticky conditions; and heavy-duty tine types with narrow reversible tips so staggered that they work well in medium-textured stony soils or cloddy heavy land.

Power cultivator – drill combinations

The compactness of many power harrows and rotary cultivators, and the very small amount of extra power needed to drill immediately behind such machines, make

cultivator–drill combinations attractive. High-powered tractors needed to operate such combinations can be designed to incorporate adequate lift capacity for both drill and cultivator, and close-coupled linkages allow the drill to be carried above the cultivator for transport. The drill's seed tubes and coulters are usually arranged to deposit the seed as the soil settles behind the cultivator – an arrangement well suited to difficult soil working conditions. Several types of power harrow and rotary cultivators can be adapted for such duty, and a light crumbler roller added to effect any necessary firming of soil around the seed without surface compaction. The drilling component can be designed for easy separation when not in use.

Operation of drills

Calibration

With all types of drill it is easy to check the sowing rate either by jacking up the drive wheel and weighing the seed delivered when the wheel is turned a given number

Fig. 7.11 Combined seedbed preparation and drilling of peas using Roterra-Combi-pneumatic drill with front transfer seed hopper FH 2000 carried on a braced frame bolted to the tractor chassis. A steerable front packer roller with scrapers covers the land between the tractor wheel tracks. The 4 m Roterra is rear-mounted, and the seed drill weight is carried on its own land wheels. Grain transfer is by tractor external hydraulic

spool valve power and centrifugal fan. A tractor of at least 75 hp is needed. An electronic monitoring system (Polytronic ii) is designed to detect obstructions between the drill distributor head and the bottom of the coulters, interruptions in the air flow, drive from the ground driven land wheel, level of seed in the drill hopper and operation of the tramlining kit and markers. (LELY UK)



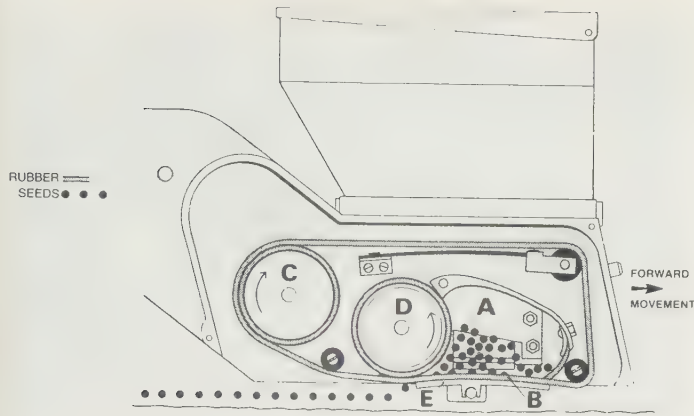


Fig. 7.12 Diagram showing main features of multi-purpose belt-feed single-seed mechanism. (Stanhay Webb S870)
 A Interchangeable choke regulates flow of seed from hopper;
 B interchangeable seed belt driven by driving wheel C moves seed to repeller wheel D which agitates seed in chamber and assists drop through apertures in belt at end of spring base E. Belt types, each with range of aperture sizes, include: (1) plain rubber/canvas for small seeds such as brassicae; (2) thicker single ribbed rubber/canvas laminated for sugar beet, etc.; (3) double or triple ribbed rubber/canvas laminated for multi-line row from each sowing unit; (4) plain rubber or plastic suitable for small seeds e.g. carrots or lettuce. Idler rollers are easily removed for belt changes and cleaning.

of revolutions, or by putting bags over the seed tubes and weighing the seed delivered when the drill is pulled for a known distance.

Equipment provided with many modern drills includes a handle and a collecting tray to facilitate stationary calibration. A preliminary check before field work begins can ensure that the seed rate is somewhere near the target.

Setting markers

For high-speed work it is usually most convenient to use a mark corresponding with the centre line of the tractor. The rule then is as follows: distance of marker from outside coulter equals half drill width plus one row width.

Unit drills for root and vegetable crops

One of the main needs of a root or vegetable drill for commercial use on a field scale is distribution of single

seeds accurately spaced along the row and placed in the soil at a uniform depth so that no hand work on thinning is needed. After the 1950s this requirement soon eliminated from serious competition any previously successful mechanisms consisting essentially of a gravity feed through a hole of adjustable size, with a rotary agitator to keep the seed flowing. Seed rate with such mechanisms is inversely proportional to forward speed. By the 1970s positive seed spacing mechanisms offered by several manufacturers could be relied on to produce satisfactory distribution of single seeds on special surfaces developed for carrying out indoor tests of seed dispensing units in laboratory conditions. However, regular sugar beet drilling field trials showed that performances of some units which were satisfactory at $2\frac{1}{2}$ mph could deteriorate seriously at desired working speed of $4-4\frac{1}{2}$ mph, especially in adverse conditions.

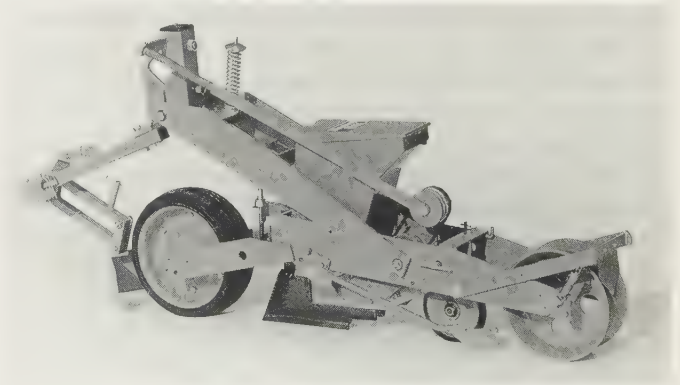


Fig. 7.13 Unit drill chassis and soil working features. (Stanhay Webb S981)

Soil working features, left to right, include:

Adjustable clod deflector which sweeps aside dried clods; large diameter front wheel with flexible tyre levels undulations; telescopic anti-bounce pneumatic suspension; coulter depth of cut controlled by large diameter front wheel; seed ejected into shielded narrow furrow is trapped there; narrow spring-loaded press wheel with soft rubber tyre removes air pockets; variable-height coverer blade fills furrow; large-diameter self-cleaning spring-loaded rear wheel provides positive control of coverer's working depth and lightly firms surfaces.

Use of a single-line coulter with ceramic tip (not shown) retains correct furrow-forming profile for sugar beet approximately three times as long as the steel coulter illustrated. Alternative double or triple line coulters may be used for multi-line precision drilling vegetable crops.

Subsequently, leading manufacturers of proven types which include cell wheels, cell discs, rubber belts and pneumatic, concentrated much development effort on such features as elimination of unit bounce by use of improved unit suspension systems, plus detailed study of soil-working features aimed at accurate control of coulter working depth, soil cover and firmness of the soil surrounding the seed.

'Single-seed' drills

The principle of operation of most 'single-seed' drills is to employ a seed ring, belt or disc with a series of slots which are just big enough to hold one seed from a carefully graded sample. The seed is carried round in the slot and is positively ejected when it arrives above the furrow opener. It is essential to have a very short drop from the seeding mechanism to the ground, so that the seeds remain regularly spaced after they have fallen into the soil. Figures 7.12 and 7.15 illustrate two kinds of mechanism working on this principle. There are several types of pneumatic mechanism which employ a difference in air pressure to hold the seeds in position in the seed cells until the discharge point is reached, and then to provide positive ejection. In a typical arrangement the vacuum exerted on one side of the cell disc is maintained by a nylon or phosphor-bronze seal over the whole of the disc

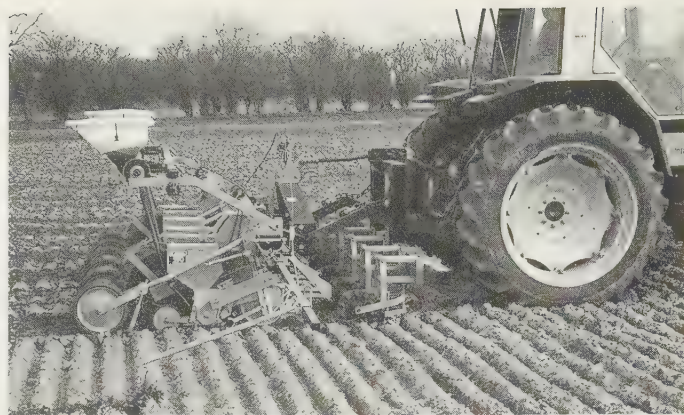
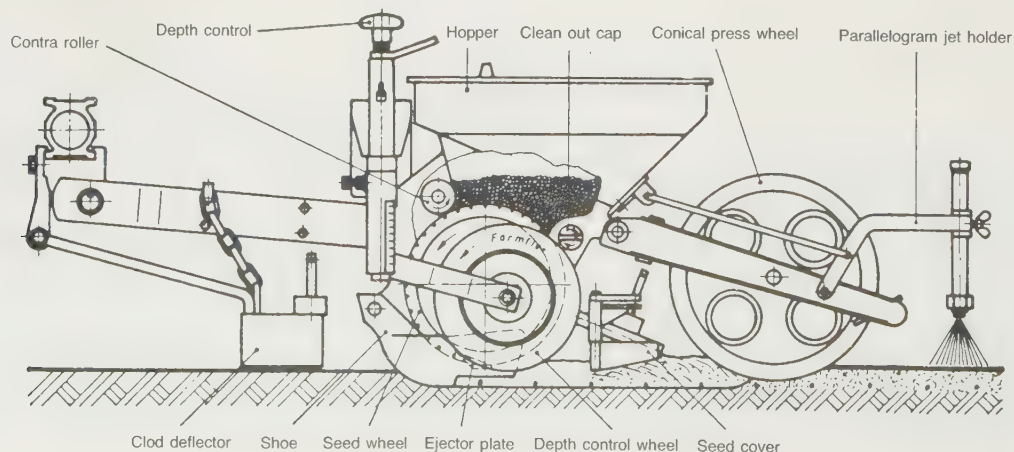


Fig. 7.14 Six-row cell-wheel drill with narrow ceramic-tipped coulters, strip-drilling sugar beet directly across furrow-pressed light land. The operation is based on careful use of the six-row peg-tooth row crumbler mounted between tractor and drill, which loosens and levels narrow strips directly ahead of each row unit. The rough surface visible on the drilled work is effective in helping to control wind erosion on blow-susceptible soil. The two granule application units cover three rows each. (Stanhay Webb Rallye 590 with C70 row crumbler)

except a small segment at the bottom, where the seed is released and drops into the coulter. A selector finger is used to remove most doubles and drop the surplus seeds back into the hopper. A powerful fan is needed to provide the vacuum on multi-row drills.

Fig. 7.15 Cut-away section of large-diameter cell-wheel feed drill showing general arrangement of smoothing, sowing, covering and firming devices. (Matco Fahse)



Main application of the vacuum principle is to vegetable or flower seeds which cannot be handled by most other drills. Multi-row units are used by specialist growers for single-seeding lettuce and very small seeds, e.g. petunia. In the 'Mini-Air' (Matco-Fahse), adjustable forks take off doubles, and nylon cut-off blocks help delivery to coulter. Clean seed, no dust, and regular cleaning of apertures are essential. Growers readily accept some trouble in achieving the degree of single-seed accuracy attainable only by purpose-designed machines.

Some seeds, owing to the peculiar characteristics of their seed coats, present special problems, and for all seeds with rough or irregular seed coats the process of 'pelleting' is attractive. Some existing drill mechanisms work very efficiently with uniform pelleted seed.

Modern pelleted monogerm sugar-beet seed produces less than 5% of doubles, while 70% of singles can be guaranteed with most polyploid varieties. Eighty per cent of the British sugar-beet crop is drilled at row widths of 460 or 510 mm (18 or 20 in), and the depth aimed at is usually about 25 mm (1 in) but may be more if the soil is uniformly moist only a little deeper. Pre-emergence residual herbicides are applied to about 80% of the total area. The most expensive herbicides tend to be band-sprayed, while cheaper ones are usually applied overall.

Single-seed drills have been found very useful for crops such as swedes, and in ideal conditions it is possible by using a wide spacing, e.g. 125 mm (5 in), to grow good crops without either hand singling or mechanical thinning. This, of course, necessitates a very good clean seedbed, and drilling must be done when moisture conditions are right.

Performance of single-seed drills under test may be assessed by actual plant emergence, but comparisons must then take account of the very variable effects of soil conditions on percentage emergence. In sugar beet, where all possible precautions are taken, average emergence may range from less than 70% to about 90%.

Current aims include avoidance of excessive loosening of seedbeds to a great depth, so making it possible to use reasonably light four-wheel-drive tractors without the risk of over-compaction adjacent to the tractor wheelings. Several farmers had successfully developed, with help from interested manufacturers, co-ordinated bed systems, e.g. with four-row beds having 40.6 cm spacing for rows within the beds and 61 cm wheeling rows suited to 12-row drilling and use of a four-row harvester. Development

trends in individual drilling units include large wheels with careful choice of tyres: a solidly built unit framework and a suspension design allowing easy floating in a vertical direction with adjustable restraints to avoid unit bounce effects on sowing depth. Vertical movement can be enough to allow effective use of a well-planned series of shallow soil-working operations in succession from front to rear of each unit, without objectionable variations of sowing depth.

A good combination of pressure spring and telescopic pneumatic damper with lateral rigidity can result in absence of bounce when working across typical furrow-press work.

An aspect of strip cultivation benefits jointly developed by British Sugar agricultural development staff and a manufacturer is typical of current trends. The Row-crumbler C70 (Fig. 7.14) cultivates only a shallow 15 cm wide band immediately ahead of each drill unit. It consists of a V-shaped clod sweep with three adjustable tines, on a parallel linkage, with a toothed cast iron crumbler roller carrying out the combined functions of controlling tine depth and consolidating the centre of the cultivated strip. Practical trials (Limb (1988)) showed that the drill coulters maintained a uniform depth more easily when the strip crumbler units were allowed to float independently of the drill units, as illustrated. On many soils, maintenance of uniform drilling depth is greatly improved by use of ceramic-tipped drill coulters.

Practical experience of application of bed systems on extremely stony land has encouraged some farmers already familiar with the advantages of stone windrowers for potatoes to adapt the system for sugar beet on soils with many extremely large flat stones. In such conditions stone windrowing in four-row beds to a depth of 10–12 cm can be worth consideration. It can help to ensure a full plant as well as to avoid rejection of loads by the factory on account of an excessive quantity of stones with the roots.

With many drills, increase of forward speed in the practical range 3 to 8 km/h causes a progressive deterioration of performance. Silsoe Research Institute work shows that this effect can be minimised by separating metering and deposition of the seed, so that the seed is always released at the optimum point.

When a gang of single-seed drill units is employed, the drive may either be by the wheels on each individual unit, or there may be a shaft which drives the individual feed mechanisms. The latter method gives a better result,

since it avoids any tendency of individual units to slip on loose soil.

Field performance is much influenced by equipment and methods used to place and firm small seeds in the soil. A good combination for typical circumstances where there is a surface dry layer is (a) a clod deflector to sweep aside the dry layer, (b) a shoe to push aside some moist soil and drop the seed well below the surface of the moist layer, (c) rear wings to sweep moist soil over the seed, and (d) a narrow rubber-tyred press wheel to firm moist soil round the seed. Another deflector may finally be used to sweep a thin buffering layer of mainly dry soil over the row.

Maize drills

The type of seed mechanism most widely used for maize in those parts of the world where the crop has been in regular cultivation for many years is a horizontal 'plate' feed, with notches of a shape and size designed to receive a single maize kernel, lying flat. The rotating plate lies at the bottom of a cylindrical hopper. The mechanism is simple, reliable and often sold at a price in keeping with the history of its development. Nevertheless, other single-seed mechanisms specially designed for maize have been developed, and include a larger version of the endless-belt type of root and vegetable drill. Hoppers, as well as seed apertures, need to be larger for maize than for most root and vegetable crops, and the coulters have to be designed to place the seed fairly deep, in order to ensure rapid germination and to minimise bird damage.

Fluid drilling

Fluid drilling consists of suspending the seed in a suitable gel, which makes metering seeds of irregular shapes easy, and facilitates pre-germination in controlled conditions, with addition of fungicides, pesticides, growth regulators and trace elements as needed. Examples of application to vegetable crops include tomatoes pre-germinated at 20°C and sown 'to stand' beneath plastic tunnels; lettuce pre-germinated at lower temperatures in mid-summer; and carrots, onions and parsnips sown to give earlier and more uniform emergence in adverse soil conditions.

Germination tanks, suspension mixer-blenders and fluid

transporter tanks have been developed to suit all common scales of vegetable production.

If field conditions preclude sowing as planned, pre-germinated seeds may be held for a few days in water in cold oxygenated storage at a temperature close to 0°C.

Specialist applications include use of automatic multiple seeding heads for sowing single pre-germinated seeds into peat blocks formed by block-making presses.

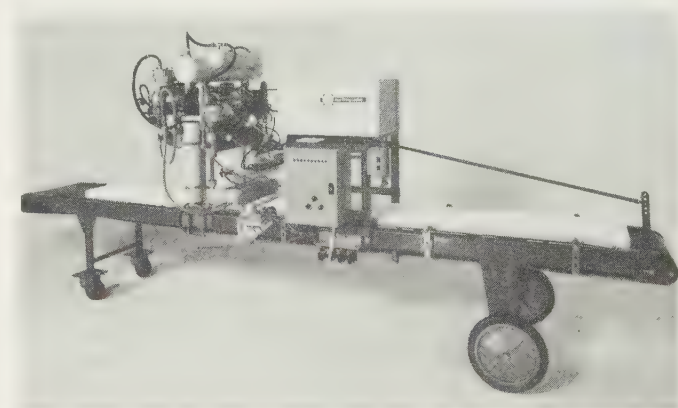


Fig. 7.16 Automated fluid seeding head mounted on mobile platform with a moving belt carrying trays which in use are filled with peat-based compost and move forward one row at a time after deposition of each line of pre-germinated seeds. (*Fluid Drilling Ltd*)

The trolley-mounted automated seeding head has lines of probes which (a) are lowered into the liquid container and suck a single pre-germinated seed onto the hole of appropriate size at the end of each probe: (b) withdraw from the liquid, deliver the row of seeds into peat blocks, release the vacuum and withdraw, leaving the seeds in the blocks. The probes are then cleaned by a short positive air blast before repeating the process as the trays automatically move forward beneath the sowing head. The technique is used for lettuce, celery and tomatoes, and also for a wide range of flowers which are later grown on by amateurs in pots and beds.

Electronic monitors for seed drills

Two main types of electronic monitors are used on unit drills to warn the operator of malfunctioning. The earliest

in common use simply detects whether the seed-delivery mechanism of each unit is rotating: a red light for the particular unit shows failure to do so.

One type of monitor that can be applied to any type of drill employs a photo-sensitive element which detects the seeds as they drop through a section of transparent tubing or through a specially designed sensor unit. The photo-sensitive element provides data on the frequency of fall of the seeds, and if this drops below the level required by the setting of a rate adjustment element in the control box, the appropriate indicator light on a console is illuminated, and a warning klaxon is sounded. Each row is monitored individually, and common failures caused by bridging or an empty hopper are immediately revealed. The console is usually mounted in the tractor cab where it can easily be seen. Power for operating the unit is provided by the tractor battery.

Independent experience shows that such equipment can give worthwhile results for all commonly used unit drill sizes up to those operated by large-scale farmers and contractors. One example, the DICKEY-john Scanamatic PM1000 (Fig. 7.17) is shown in six-row form as used successfully on sugar beet at Broom's Barn Experimental Station. Such equipment used with a Stanhay-Webb drill was found capable of almost guaranteeing satisfactory plant stands. Mounting of sensors is individual to make and model of drill. Pressure sensitive switches enable the operator to enter row width and ground speed, and later to scan individual rows for seed population, and final

average population for the whole drill, using liquid crystal display located lower left on the front panel. Naturally, accuracy of the speed and width constants entered determines reliability of the read-outs.

Grass seed drilling

Requirements for sowing grass vary considerably with the climate, especially the rainfall. As a general rule, broadcasting on the surface followed by a light harrowing and rolling can be quite satisfactory in the west, whereas in drier regions it may be essential to drill the seeds into moisture. Grass seed must not, however, be drilled too deep: 13–19 mm ($\frac{1}{2}$ – $\frac{3}{4}$ in) is usually suitable. Special-purpose grass seed drills with small shoe coulters spaced 90 mm (3.5 in) apart were formerly used, but the advent of general-purpose drills with coulters only 90–130 mm (3.5–5 in) apart has made these obsolete. A typical modern drill with studded or fluted roller feed and attached harrows is well suited to the job. Other methods of drilling include use of a grass seed box attached to an ordinary corn drill. With this combination the normal method of use is to allow the seed to fall on the soil surface between the coulters. Some of it is covered by the action of the coulters and some by the harrows which usually follow. A final rolling is usually desirable when grass seed is sown, whatever the drilling method.

Broadcasting

Just as the advent of multi-purpose drills has tended to make most specialised grass seed drills obsolete, so also has the widespread use of fertiliser broadcasting machines that can sow seeds made it less essential to have special-purpose seed broadcasting machines. Nevertheless, there is still a useful place on many farms for various kinds of 'full-width' broadcasting machine, most of which have a brush feed. The long seed box may be tractor-mounted and pto-driven (e.g. Alvan Blanch), mounted on wheels which drive the mechanism, or on a hand-pushed barrow frame. With tractor mounting, covering by harrow and roll may be done at the same time. The seed is pushed from the box through a series of circular apertures, the size of which can be readily adjusted for different seeds and seed rates. The brush feed works well while the

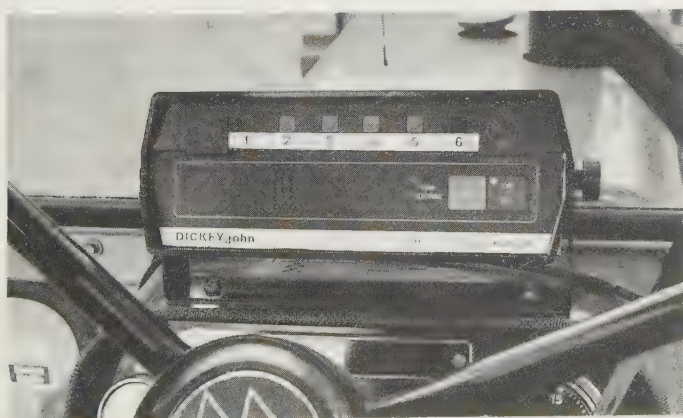


Fig. 7.17 Control console of microprocessor mounted in tractor cab for checking performance of 6-row Stanhay-Webb sugar beet drill. (DICKEY-john Scanamatic PM 1000)

brushes remain in good condition, but is not reliable when they are worn. They, are however, easily and cheaply replaceable.

A small broadcasting device called the 'fiddle' is preferred by some farmers, especially for hillside work. This machine, consisting of a hopper and a mechanical distributor, is strapped to a man's shoulders. As the sower walks along he draws to and fro a 'bow', which causes a small ribbed platform to rotate and fling the seeds out to the sides. Heavy seeds are, naturally, thrown farther than light ones.

Many farmers have found that they can sow grass and clover seeds quite efficiently with their fertiliser distributors. Most modern distributors that are in good order may be used. The advantage of broadcasting over drilling for grass and clover seeds is that in good conditions a more complete covering of the ground is achieved.

Though in wet conditions in late autumn cereal seed can be broadcast rapidly by bulk handling techniques using fertiliser distributors, covering is not easy and it is difficult to achieve results comparable with those from drilling. When broadcasting is practised in good seedbed conditions, it is desirable to have a reasonably firm seedbed, so that the tractor does not make deep ruts; and where practicable it is advisable to pull light harrows behind the tractor in order to fill in the wheel-marks before the seed falls into them. There remains the problem of how to cover the seed. It is normally necessary to carry out effective harrowing, and a typical need is to use a spring-tine cultivator-harrow with levelling harrow attached. It should be understood that this kind of treatment cannot result in the uniform sowing depth which can be achieved by drilling; and in consequence it is usually advisable to use a higher seed rate, e.g. 20% more than that necessary for drilling. Trials at experimental husbandry farms have shown that it is possible to secure as high yields by broadcasting as by drilling; but the whole technique involved in broadcasting requires more skill and judgement than drilling, and on average is likely to lead to reduced yields.

Potato planting

Results achieved in potato planting by machine depend on complex relationships between the technical quality of machine performance and ability to work fast with a

minimum demand for labour. Automatic planters of the belt feed type tend to give a less even distribution than hand-fed semi-automatic machines or cup-feed types; but they can make up for this by 'timeliness' of planting. Damage to chitted seed tends to be high with some automatic cup-feed types.

Typical recommendations for planting procedure on difficult soils are:

- Plough early in autumn in reasonably dry conditions.
- Limit spring cultivation to the depth of the frosted tilth.
- Use a wide row spacing e.g. 915 mm (36 in) to reduce depth of work needed to form a good ridge.
- Use power-driven tined implements to reduce unnecessary soil compaction.
- Set up good ridges to avoid greening of tubers.
- Use a residual herbicide just before crop emergence and avoid any unnecessary after-cultivations.

Recommended seed numbers for normal-size seed range from about 35 000/ha (14 000/acre) to 52 000/ha (21 000/

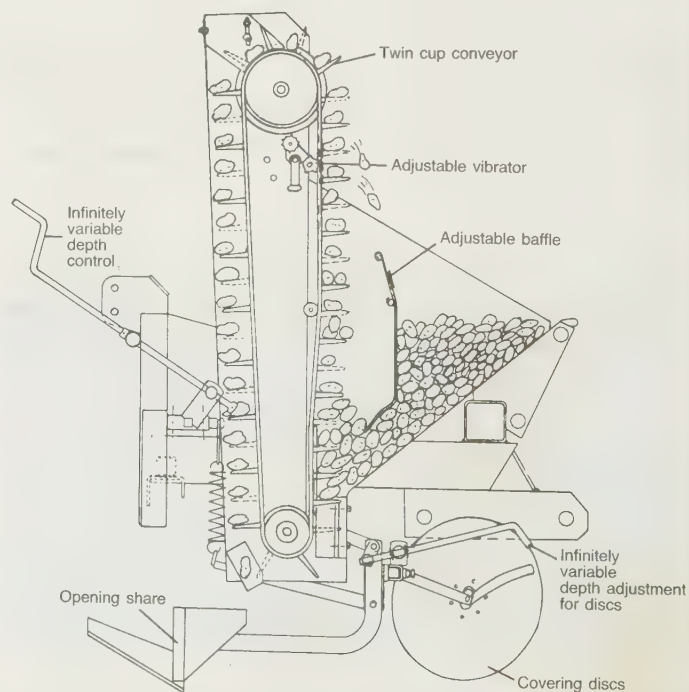


Fig. 7.18 Section showing general arrangement of mechanisms in an automatic potato planter with twin-cup conveyor (*Hassia*)

acre). At normal size : weight relationships the quantities needed range from 2500–3720 kg/ha (1 to 1.5 tons/acre).

Semi-automatic planters

With planters of the semi-automatic type, the potatoes usually have to be placed in cups by operators sitting on the machine.

The speed at which hand-fed planters can work is governed by the fact that operators on most machines cannot handle more than about 120 potatoes per minute; and at 460 mm (18 in) spacing this results in a forward speed of not over 3.2 km/h (2 mph). The rate of work is, of course, influenced by the operator's working position and by the exact movements that have to be performed, and there is variation between different machines in this respect. There is also a good deal of variation in the accuracy of spacing, this depending on whether there is appreciable wheel slip and on whether the potatoes are allowed to roll in the furrow bottom. Use of hand-fed planters rapidly declined when reliable automatic machines became available, even though the quality of work done by the new machines was sometimes poorer.

With planters of the 'assisted feed' type, there is an automatic feed mechanism which picks the seed out of a hopper and then passes it in some kind of conveyor in front of the operator, who can correct any misses or doubles. This type of machine is capable of good work with well-graded unchitted seed.

Automatic planters

Cup feed: The basis of a commonly used and reliable general design is a slow-moving belt with a double row of cups for each row of potatoes. There is usually provision in each cup for some variation of size of insert to suit the seed size. The cups move upwards through a small feed section of the hopper, holding just enough potatoes to ensure that each cup picks up at least one tuber. During elevation there is usually a definite and controllable knock to remove the second tuber if two are picked up. Such a mechanism can plant up to 500 tubers per minute per row, giving a potential work rate in the region of 1.5 ha/hr for a four-row planter working at 6.5 km/h, allowing 30% 'turn-round' time. Two-row planters are usually mounted, four-row either trailed or mounted and six-row normally trailed. In the larger sizes the main hopper may



Fig. 7.19 Two-row automatic planter with toothed drive pulleys and planting belts fitted with standard cups which accept a choice of two optional inserts for smaller seed sizes. A three-stage adjustable agitator working on the inside of the belt minimises planting of doubles. Traction tyres provide a positive drive in most conditions. The optional fertiliser placement attachment located just ahead of the seed hopper has four narrow spring-mounted shoe coulter which place the fertiliser bands from 75 mm (3 in) to 115 mm (4½ in) on both sides of each row centre. Folding hopper side extensions can be raised to facilitate hopper filling from large boxes or loader buckets. (Reekie)

be hydraulically lowered for filling and gradually raised as necessary to maintain a flow to the feed mechanism during work. In deciding choice of type and size, the question of other operations including application of fertiliser and micro-granular insecticide needs to be considered. Potato planter monitors can provide a fairly easily operated and useful reasonably priced means of securing improved performance from well engineered modern automatic planters. A typical example, the RDS Computater (Fig. 7.20) provides six channels of information comprising Forward speed, Area, Seed spacing, and Planting rate (Seeds per Acre or Hectare). In addition, up to four rows are continually scanned, and if more than three consecutive tubers are missed, the chevron in the display moves to indicate which row has a fault, the display flashes, and an audible alarm sounds.

The Computater is normally operated with forward speed displayed: other channels are selected by pressing the chevron button, bottom right. The individual rows normally show seed spacing. Population count is obtained by pressing the POP'N button.



Fig. 7.20 Potato planter monitor as mounted in tractor cab, for finger-tip operation. The monitor is normally operated with forward speed displayed, as indicated by the small black chevron above the extreme left channel. Moves to other channels are by pressing the white chevron in black surround (see text). (RDS 'Computater')

With a good sample of seed a keen manager or operator can obtain early indication of sowing rate and spacing, and can make any necessary adjustments to ensure that the seed bought is evenly sown on the land available. The Griffith-Elder type H400 and a more comprehensive FH400 were developed with the help of Walker Crisps before 1987 when the two models were launched. The FH400 includes distance travelled (km or miles) and seeds per hectare or acre among items available on display.

Growing potatoes in multi-row beds as opposed to single rows has become a practical proposition on friable soils, especially where stone or clod windrowing has been employed in bed preparation. Many unmanned harvesters are capable of dealing easily with flat-topped beds at 1.83 m (6 ft) centres and about 1.53 m (5 ft) shoulder-to-shoulder. Three-row automatic planters specially developed for the need may have the tubers of the centre row staggered to provide equidistant spacing in the beds. Chief advantages are better resistance to washing away soil by repeated irrigation resulting in fewer green potatoes.

Some automatic planters of other types aim to perfect the metering process by employing a slow-moving trans-

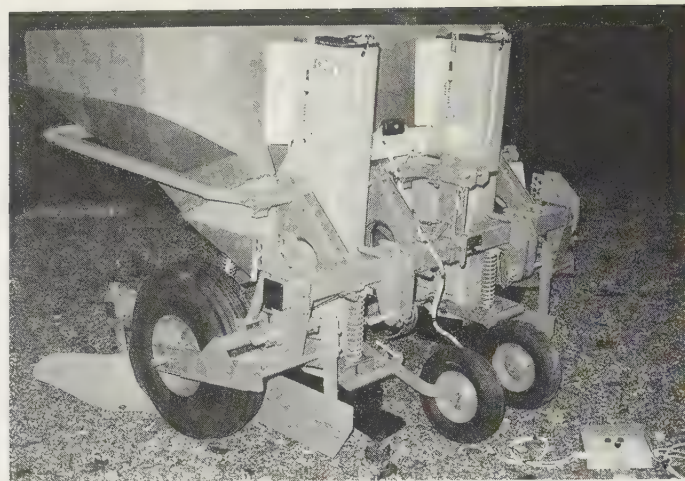


Fig. 7.21 The big-hopper two-row automatic potato planter equipped with wide depth wheels holds up to 18 cwt (907 kg) of potatoes. Each feed belt has two rows of cups, slightly staggered, with choice of size and shape to suit the seed. Side shields hold the bed in position during planting. For planting chitted seed an electric motor-driven vibrating hopper bottom can be fitted to reduce the quantity of seed through which the cups pass. (KeyAg-Gruse)

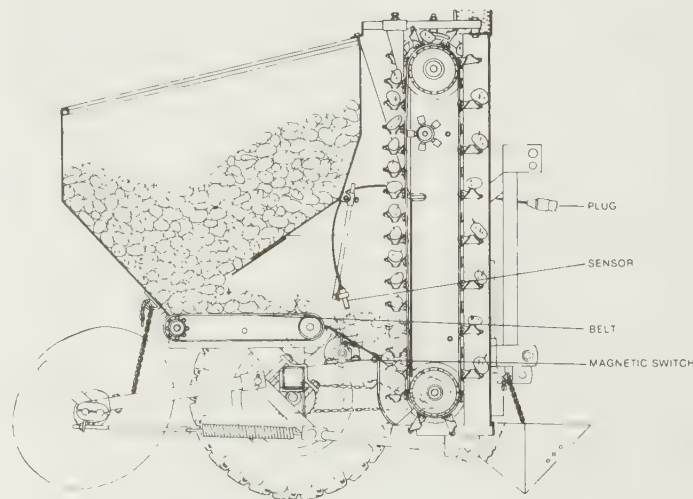


Fig. 7.22 The Standen-EHO 242 S is a two-row automatic planter designed for use with unchitted or chitted seeds, at output of about 1 acre/hr. The hopper design with large capacity, gentle slopes and large, easily adjustable outlet onto slow-moving belt with electronic control, aims to minimise damage to chits in transfer to the twin-cup elevator. Options include fertiliser placement and choice of ridging or disc covering bodies. (Standen-EHO)

verse belt in the early stage of movement from the hopper and a positive arrangement of the tubers in compartments near the delivery point. With tuber spacings normally aimed at, occasional single gaps have little effect on yield due to compensating growth by neighbouring plants, but repeated longer gaps inevitably reduce yield appreciably.

Some automatic planters tend to cause damage to normal chitted seed, and this can lead to gappiness or uneven emergence, especially with some varieties. One way of overcoming these difficulties is to secure very good control of the environment of the chitting house, and to delay chitting until just before the tubers are required for planting. Thus, the crop will be planted with the 'eyes' only just open, but with almost a certainty that damage to the chits will be avoided, and that rapid growth will take place.

Potato planter filling

Mechanisation of planter filling aims at speeding up work rates while reducing damage to the chits. A system developed by the Scottish Centre of Agricultural Engineering employs either $\frac{1}{2}$ tonne bulk boxes or chitting tray containers, both top-hinged and split vertically to empty. The full units are placed by fork-lift on two pivoting goalpost-type frames which are fitted to the planter hopper and can be opened or closed by hydraulic cylinders. The bulk boxes may be filled at the store or on the headland from sacks or trays; the split chitting trays have to be filled layer by layer before chitting. Damage to chits during emptying is minimised by keeping the planter hopper as full as practicable to limit the drop.

Stone and clod windrowing

Stone windrowing before planting has rapidly become widely practised on light soils from which the stones are easily separated. In some conditions it is practicable to remove almost all stones above about 30 mm size from the ridges where the crop is to be grown. The basic principle is simple: the whole of the soil to be lifted at harvest is passed through the windrower; the stones are removed by a separator web of the required spacing; and the separated stones are buried in a specially prepared furrow where they can remain undisturbed until harvest is completed. Benefits are that unmanned harvesters of a simple type can be used, the lifting operation is greatly



Fig. 7.23(a) The rotary bed tiller comprises a sturdy horizontal-axis rotary tiller with heavy-duty four-speed gear-box and a rotor consisting of spirally arranged hardened steel tines, with adjustable tilth boards for clod shattering. The deep ridging bodies seen are fitted with shear-bolt protection, and for particularly rocky conditions hydro-pneumatic bodies are an option. The equipment can be used in over-wintered or spring-formed beds where cultivation is necessary before stone or clod windrowing. (*Reekie Bed Tiller*)



Fig. 7.23(b) Stone and clod separator with floating intake rotor and long adjustable scrubber/clod crusher web above the steeply sloping rear web. Three rows of hydraulically actuated pressure pads are located above the floating web to improve separation in damp or cloddy conditions. The machine is seen working on the deep-ridged forward burial system. (*Reekie 330 SA*)

speeded up, and crop damage at harvest can be substantially reduced.

In a common working system the separator works on a pair of ridges or a bed immediately ahead of the two-row planter, and delivers the stones by cross conveyor into a



Fig. 7.24 Stone/clod separator working ahead of two-row planter. As seen here, clods are conveyed forward to furrows prepared by bed-former, which on heavy soils can set up the beds in autumn. Tractor wheels run over the clods/stones on the next bout, and the planter tractor wheels follow along the same rows. (Pearson/Grimme)

furrow beyond the two rows just planted. Advantages include minimum loss of soil moisture. Main disadvantage is that it is impossible to press ahead with windrowing when soil conditions are ideal; and overall work rate is limited by the planter speed and the stops for refilling that are unavoidable. Work methods that permit the windrower to operate well ahead of the planter have obvious attractions. In one system that permits this there is a preliminary bed-forming operation in which a deep trench of loose soil is created between the beds by a subsoiling tine. The windrower places the separated stones

in these channels by means of a horizontal reversible conveyor which delivers them beyond the bed to be worked next, so that the tractor and windrower always run on two stone windrows, and so press them into the soft soil as the stone-free ridges are prepared. This system fits in well with trends regarding row spacing, with two rows at 0.86 m (34 in) spacing between wider (38 in) tractor wheel rows at 1.83 m (6 ft) centres. Alternatively a three-row bed may be employed at the same wheel track width.

A third working system used occasionally where the proportion of stones is very high involves depositing the

separated stones in every furrow. Where the quantity of stones to be windrowed exceeds about 250 tonnes/ha (100 tons/acre) stone removal as a preliminary operation on the worst areas can be carried out by some machines which can be fitted with a side-loading elevator.

In a typical windrower a power-driven spiked rotor works above the share, and is driven at a speed high enough to assist the intake of the ridges or bed, reduce draught and break up clods. Others employ a series of stationary stiff rubber fingers above the web to assist separation. At the rear, there may be rotating spools to separate the largest stones in to a small hopper.

On clay and heavy silts where potatoes are grown, intractable clods can be a serious problem. A clod removal machine is most effective if two-row beds at 6 ft centres are set up in autumn and the windrower is used in spring with the unbroken clods delivered into 38 in tractor wheel rows. An effective clod reduction mechanism consists of two steeply inclined short elevator chains with another web suspended above, and a reversible conveyor for clod delivery (Figs 7.23(b) and 7.25).



Fig. 7.25 Mounted stone and clod windrower working well in cloddy conditions where two-row beds are to be formed. A set of seven split shares and adjustable discs lift the bed soil on to a steeply sloping agitated digger trace above which an adjustable scrubber trace is suspended. The machine is shown with hydraulic reversible cross conveyor delivering separated clods into a pre-formed deep furrow in which the tractor wheels run on the next bout. (KeyAg Squier 'Clod Master')

Fertiliser and insecticide placement for potatoes

Many experiments in Britain have shown that it pays to concentrate the fertiliser near to the row of seed, though preferably not directly in contact with it. Drilling all the fertiliser in a concentrated band with the seed sometimes gives good results, but is unsafe, since it may cause serious scorching and reduction of yield in a dry spring. Several planters have coulters designed to secure side-band placement, the usual aim being to place a continuous band of fertiliser about 75 mm (3 in) from the row of seed and at approximately the same level. The best position for fertiliser placement depends to a certain extent on the soil type, the type and amount of fertiliser used, the time and depth of planting, and the weather conditions in spring and early summer. There is, therefore, much to be said for machines in which the placement mechanism has a fairly wide range of adjustment.

Where a planter without a fertiliser attachment is used in conjunction with an ordinary fertiliser distributor, satisfactory results may often be achieved if the fertiliser is well worked into the soil, the potatoes are planted fairly shallow and the covering bodies are set to draw the surface soil near the seed, deep ridging being carried out as a subsequent operation.

For farmers who use liquid fertilisers there is fairly simple equipment that can provide accurate placement where one of the more common types of planter is used. The fertiliser tank or tanks are usually forward or saddle-mounted on the tractor, so that they help to counter-balance the substantial weight of a mounted planter with full hopper.

Equipment for application of granular insecticides and herbicides is dealt with in Chapter 9. Insecticide granules are commonly applied directly on the seed during planting. Most modern planters provide for fitting of the specialised distribution equipment needed.

Transplanting machines

Transplanting machines may be broadly grouped into 'hand-fed', 'mechanical' and 'automatic'. In the first type the operators sit on low seats on the machine and drop the plants by hand direct into a furrow of suitable depth and width, made by a hollow coulter. A pair of press

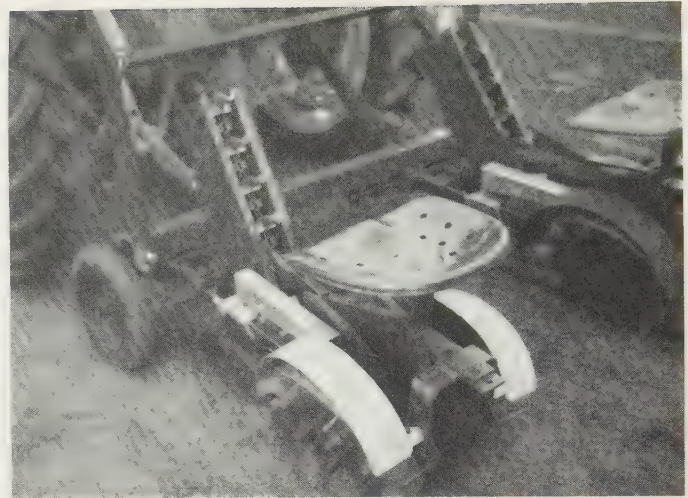
wheels usually follows and compresses the soil around the plants.

Hand-fed planters must normally be pulled very slowly, speeds as low as 1–2 km/h ($\frac{3}{4}$ mph) often being called for. The forward speed at which any planter can work naturally depends on the spacing of the plants and on the number of operators who can work on one row. With hand-fed machines a common procedure is to have a two-row outfit with one man planting each row and a third handing the plants to them. With mechanical planters, two or sometimes more people can work on each row. Operators place the plants in trays or between fingers on an endless conveyor, and from this point the plants are dealt with entirely mechanically. The conveyor takes them down to an open furrow, where they are released in the correct position and surrounded by soil (Fig. 7.26). The chief advantage of this method over the hand-fed one is that the forward speed of the outfit need not be as low, and that unskilled labour may be employed after a very short training.

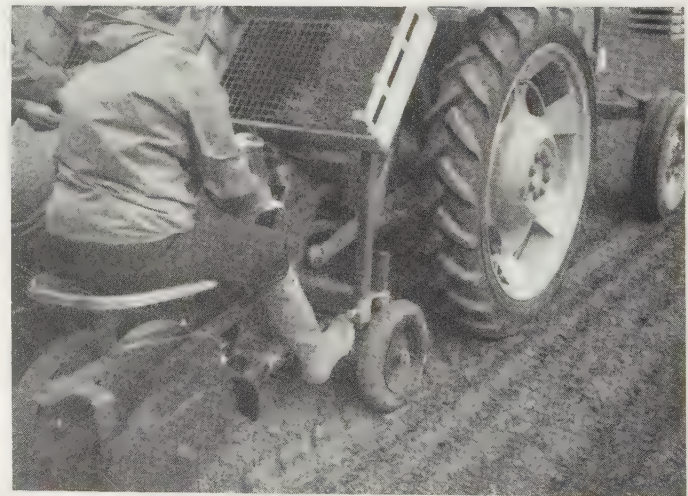
With some mechanical transplanters a device for watering each plant just before the soil is pressed around it may be fitted for use in dry ground.



Fig. 7.26 Four-row transplanter planting cauliflowers.



(a)



(b)

Fig. 7.27 Hand-fed 'module' transplanter for use with plants grown in small seedling blocks.

(a) Basic components: the seedling blocks for each row are placed in carriers on chain conveyors geared to regulate plant spacing.

(b) Working: with the root block placed forward, the foliage is gripped by flexible steel feed discs: the blocks are placed in furrow cut by share, and the plant released after firming by inclined press wheels.

A vertical rotating carousel is provided (not shown) to carry four light module planting trays per row. (Ferrag/Accord)

It is now a well-established fact that in adverse planting conditions the work done by mechanical transplanters is often appreciably better than that done by good hand workers, even if no watering device is used. Where watering is necessary, a device on a transplanter which puts the water exactly where it will do most good – i.e. under the ground and in contact with the plant roots – is a great advantage.

A development of some significance is an increasing tendency to sow Brassica crops using a spacing drill, and to thin as necessary. Chemical weed control and improved spacing drills make such techniques more practicable than formerly.

Setting out plants grown in soil blocks poses transport and handling problems, and requires special equipment. One specialist machine for use on level, well-prepared beds, consists of a simple self-steering wheel driven self-propelled machine of very low power and forward speed which forms shallow furrows and covers the blocks placed directly in the furrows by the low-seated operators. The machine follows marks made by the tractor wheels when forming the beds. A more complex solution developed by the Silsoe Research Institute provides automatic planting, which can be carried out at much higher speed and with lower labour inputs.

Fully automatic planting generally restricts choice of methods to either 'bandolier' or 'chain-pot' systems specific

to the machine and crop. Acceptance of such systems requires expensive resources for growing the plants in a nursery and handling them to planting machines. These costs tend to limit commercial application to intensively managed glasshouse enterprises where justification involves maximising output from fixed-cost overheads without excessive demand for costs such as manual labour.

With manually-fed transplanters handling plants such as leeks at a short spacing distance, the limit of capacity per operator is about 2000 plants/hour. This can be reduced by 25% by stops, wide spacing, or plants not easily handled. The uniformity provided by raising plants in suitable blocks, often of multiple plant size in the case of onions, can greatly increase work rate even with manual feeding into a machine equipped with a suitable endless chain feeder (see Fig. 7.27).

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Equipment for Distributing and Treating Manures

An essential feature of all permanent systems of farming is the return to the soil of the nourishment taken from it by the crops that are removed. This is commonly done by the application of farmyard manure, liquid manure and artificial or organic fertilisers. The distribution of each of these categories of manure presents its own problems, which are discussed separately below.

Distribution of fertilisers

The main methods of applying fertilisers to crops include:

- Broadcasting solid or liquid fertiliser and sometimes working it into the soil before sowing.

- Injecting liquids or gases into the soil before sowing.

- Applying the fertiliser (usually solid) at the time of sowing, either in contact with the seed or quite close to it.

- Surface distribution (liquid or solid) to a growing crop.

- Injecting the fertiliser (mainly liquid or gas) into the soil in or alongside the growing crop.

Much experimental work has been carried out with the aim of determining what evenness of distribution is required and what patterns of distribution are acceptable. The results leave some doubt about minimum standards in borderline cases, but some broad conclusions which may be drawn are:

- Lack of uniformity at moderate fertiliser application levels should not exceed $\pm 10-15\%$ in good conditions of level land and little wind.

- Regular distribution in lines or bands up to 150–380 mm (6–15 in) apart can be satisfactory for many crops.



Fig. 8.1 Twin-disc fertiliser distributor undergoing manufacturer's Technical Services Division field tray test for calibration and evenness of distribution. Results are weighed and recorded in detail in the field, and later analysed and printed out in histogram form by a computer with specially designed computer programme used for controlled tests in a large purpose-built test laboratory. (*AMAZONE ZA-U twin-disc spreader*)

An uneven pattern in wide bands is not acceptable unless closely related to corresponding row spacing.

These criteria should be borne in mind in examining performances of individual types of distributor.

Most fertiliser distributors are broadcasting machines, and the object is to secure a uniform broadcasting of the manure over the surface of the soil. Some fertiliser companies offer a spreader calibration service which provides a check on distribution pattern and a diagnosis of any reasons for inefficiency. In considering the generally small cost of such a check, it should be noted that there can be appreciable yield reduction before there is visible striping.

Even new machines can be faulty due to a minor accident to a vulnerable part such as a delivery disc or a deflector plate.

Mechanical handling of solid fertilisers

Much of the fertiliser used on farms is delivered by the merchant in 50 kg bags, which are usually made of polythene or similar damp-proof materials. The tasks of stacking the fertiliser, storing it, reloading, transporting to the field and transferring to the distributor represent sizeable mechanical handling problems on many farms. Farmers and growers who handle other materials on pallets may find this system convenient for fertilisers. The bags are generally laid flat and stacked three bags high on the pallets. There is no difficulty in placing three loaded pallets in a stack. This method has the merit of keeping the fertiliser in an easily measured form, permitting an accurate check on distribution rate. It eliminates the hardest work.



Fig. 8.2 Mounted fertiliser distributor with oscillating spout delivery. Hopper can be mounted on a high-lift frame for top-dressing at late growth stage. (Vicon Varispreader)



Fig. 8.3 Four-wheel-drive LGP ATVs are increasingly used for early spring distribution of fertilisers on soft wet soils. The Kawasaki and four-wheeled engine driven Logic 40 combination with Vicon distributor is typical of equipment successfully used.

Bulk handling and big bags

On many farms the most attractive method of handling the fertiliser is in bulk. Modern granular fertilisers are free-flowing when delivered, and can be kept in good condition for long periods if protected from damp by storing on a damp-proof floor and covering with a polythene sheet. A simple method of storage and handling is to dump the fertiliser in a flat-floored bay with three retaining walls, and to remove it for use by a tractor hydraulic loader fitted with a bucket, but the method has been largely superseded by pallets and air-tight big bags (see Fig. 8.5).

Where bulk handling is to be practised it is advisable to use a distributor with a hopper of large capacity. With a 1500 kg (30 cwt) hopper and the fields not more than about 0.8 km ($\frac{1}{2}$ mile) away, it is best to fill the distributor at the store and to run back for reloading.

Other methods include use of a high-lift tipping trailer with a flexible chute for delivery from an adjustable opening in the rear of the trailer body. 'Big bags' of about 750 kg to 1 tonne capacity provide a quick turn-round at the spreader and are well suited to farmers with a specialist fork lift handling vehicle of general-purpose type, preferably with extendable parallel lift. The strong polypropylene outer bag usually has a circular hole in the bottom and an expendable inner bag.

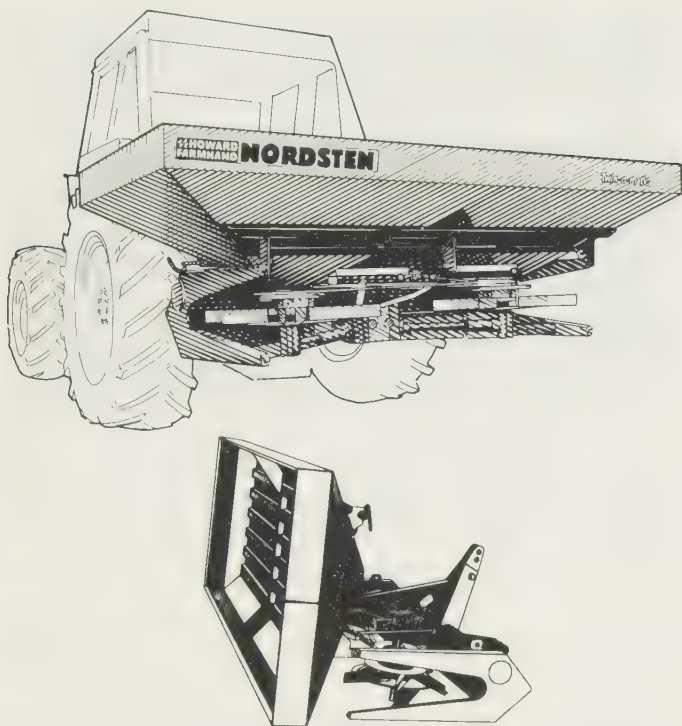


Fig. 8.4 Twin-disc distributor designed for 10–24 m spreading widths, shown (inset) with hopper vertically tilted to rear for easy cleaning. (Howard Farmhand-Nordsten)



Fig. 8.5 On a large-farm scale fertiliser handling is an operation that benefits greatly from use of a handling vehicle with all-wheel steering and a telescopic boom with long reach and adequate lift capacity. For machines with a large bulk hopper, use of big bags is increasing, but pallets have advantages for high storage. Handling vehicle illustrated is the Teleporter 2 equipped with single joy-stick 'solo' boom control. (Originally made by Sanderson)

Distribution of fertilisers by aircraft is widely practised in New Zealand. The usual flying height is little more than 9 m (30 ft), and the swath covered is about 8 m (25 ft) wide. The method is particularly applicable to areas, such as steep land, which are inaccessible or difficult of access to ground equipment. Aircraft cannot compete with more conventional methods on land on which tractors can operate.

Handling and distribution of liquid and gaseous fertilisers

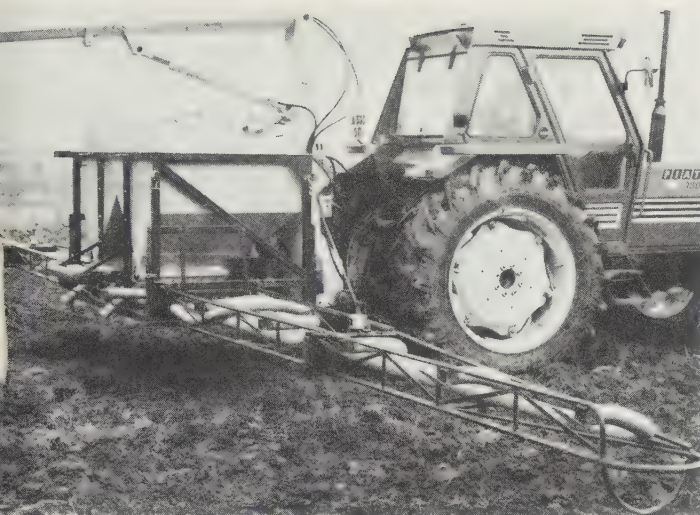
Fertilisers can be applied as solutions: and ranges of solutions of single constituents and of N–P–K mixtures comparable with solid compound fertilisers are available. Suspensions up to 30% more concentrated than completely dissolved liquid fertilisers can be used, provided that both distributors and storage systems are specially designed to handle them. Transport costs are thereby reduced. General advantages of liquids include the possibility of high accuracy of application, and no lifting work required from the operator. Some liquid fertiliser suppliers offer an attractive service that includes provision of an up-to-date distributor and its effective maintenance. Factors that need to be checked include the cost of providing necessary on-farm storage, and the overall cost per unit of nutrients applied.

Application of liquid fertiliser to growing crops can introduce problems of scorching, but such damage can be minimised by use of a suitable dribble-bar in place of spray nozzles.

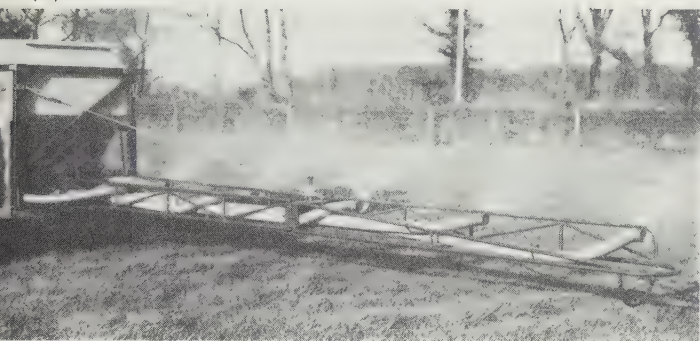
One of the commonly used liquids is aqua-ammonia, a solution of NH_3 in water. A mixture of one part NH_3 to three parts of water provides a liquid containing 20.5% N.

The equipment for applying liquid fertilisers consists essentially of tankers for transport, holding tanks on the farm for temporary storage and a distributor which may be capable of broadcast application, or below-ground placement. The problems of broadcast application are exactly similar to those which arise when field-crop sprayers are used. Materials resistant to corrosion must be used. Application rate is determined by forward speed, nozzle size and pump pressure (normally very low).

Liquid fertilisers are sometimes applied by means of a very simple type of ground-driven peristaltic pump



(a)



(b)

Fig. 8.6 Pneumatic-delivery linkage-mounted spreader with 1.3 tonne hopper designed for use with $\frac{1}{2}$ tonne fertiliser bags (*Britag Magnum*)

(a) Bag handling by simple hydraulic crane attached to three-point linkage; the box section jib is raised by a single-acting hydraulic ram. A double-acting ram is used inside the jib arm to telescope the jib for safe emptying.

(b) Type of distribution achieved by the stainless steel impact plates with a 12 m boom.

(squeeze pump) which provides a positive-displacement effect and simplifies adjustment of application rate. More usually, centrifugal or diaphragm pumps are employed. The distributor usually has a large corrosion-resistant tank mounted on a trailed chassis. The wide spray-boom is fitted with stabilisers to minimise bouncing on rough land. Application rates are usually about 168–1100 l/ha

(15–100 gal/acre) and this provides for dressings equivalent to about 188–2500 kg/ha ($1\frac{1}{2}$ to 20 cwt/acre) of solid fertilisers. Contractors can cover up to about 40 ha (100 acres) per day.

Below-ground placement of liquid fertiliser is usually associated with either drilling or potato planting. The tank or tanks in this case are normally mounted on the tractor – either as saddle-tanks or as a front-mounted tank which can balance the rear weight of a heavy mounted potato planter. Simultaneous loading of fertiliser and seed maintains the weight balance and speeds up the work. Liquid fertiliser bands for potatoes are usually located about 75 mm each side of the seed and 75–150 mm below the seed level.

For farm storage of liquid fertiliser butyl rubber bags may be used alone for small quantities, but for larger sizes a mild steel shell lined with butyl rubber is preferable.

Anhydrous ammonia is used as a nitrogenous fertiliser on a considerable scale in the USA and on a limited scale in several European countries. Ammonia is a gas at normal temperatures and atmospheric pressure, but is handled as



Fig. 8.7 Load platform-mounted 24 metre pneumatic fertiliser spreader with a 'vario-drive' system to enable the driver manually to adjust fertiliser delivery rate to match forward speed. An alternative attachment with microprocessor provides automatic correction for forward speed variations on slopes. The six-section boom is hydraulically folded for transport, with the central sections vertical and the two outer sections on each side running forward above the cab roof to rest on the support at the front of the tractor. (*Amazone*)



Fig. 8.8 This self-propelled 'Tramliner' high-capacity sprayer with 24 m boom of advanced design can be equipped with closely spaced 'stream' jets for nitrogen top dressings. The

Chafer 'Contour' active boom suspension system can lead to increased work rate, greater accuracy of application and easier operation. (*Chafer*)

a liquid under pressure in special cylinders or larger pressure tanks 125 psi at 75°F (about 8 bar at 22°C). It contains 82% N and is a relatively cheap source of nitrogen, but is not the easiest material to transport and store. The liquid is allowed to vaporise from injectors which are usually situated behind cultivator tines or knives a few inches below the soil surface. The gas is immediately fixed in the soil, and in normal operating conditions practically none escapes to the surface.

There is experimental evidence that the deep injection can in some conditions result in the fertiliser being more readily available to the roots of crop plants, especially

when the surface soil is dry. There are, however, real difficulties in injecting the fertiliser into land which has set hard owing to lack of rain, and extension of use in Britain is unlikely.

Fertiliser distributors

A fertiliser distributor for general use should be capable of uniformly distributing quantities varying from 125 to over 1900 kg/ha (1 to over 15 cwt per acre), with easy adjustment of the rate of sowing. It should deal satis-

factorily with fertiliser in poor condition, should be simple in construction, easy to operate and easy to clean. There should be few moving parts in contact with the manure, and these parts should be resistant to corrosion.

Distributors may be broadly grouped into (a) 'full-width' types in which the long, low hopper is as wide as the bout width; (b) bulk hopper types in which the fertiliser is propelled through the air over a wide bout; and (c) bulk hopper types with a wide boom arranged to provide uniform delivery from several points across its width, usually by means of an air stream. Within each of these groups the smaller machines are usually tractor mounted, and the larger are normally on a two-wheeled trailed chassis. The common mechanisms used with full-width hoppers are first considered, but are mostly obsolete.

Roller feed

A delivery roller rotates at the bottom of the box with an action similar to that of an external force-feed drill. The roller may be smooth, corrugated or spiked, and generally has a cleaning mechanism to brush or scrape off the manure when it has been carried outside the hopper. The rate of sowing is controlled by the speed of the roller and the size of the slots through which the fertiliser is delivered. An agitator of some kind may be used in the hopper of this and of most types in which the feed mechanism is at the bottom of the hopper. In combine drills there is advantage in use of a standard type of fluted roller for both seed and fertiliser.

Conveyor and brush feed

In this type, used mainly for hand-pushed horticultural distributors, the bottom of the hopper is formed by a wide belt conveyor which carries a layer of fertiliser through an adjustable opening to a revolving cylindrical brush. The brush sweeps the conveyor clean and scatters the fertiliser.

Broadcasting machines: spinning disc delivery

This type of machine has a hopper, often of truncated cone shape, situated above a disc which rotates at high speed. The fertiliser is agitated in the hopper and is fed in a stream, either by gravity or by a finger wheel or

conveyor mechanism, on to the rotating disc, which distributes it by throwing it from the edge. In good weather conditions and with careful operation the best of these machines can give a reasonably even distribution, but may give poor results with mixed manures and in windy weather. Machines with a more or less positive feed, e.g. by an auger or chain, from the hopper on to the rotating disc, tend to be more predictable as to distribution rate than those which rely on a gravity feed.

Modern machines which have been developed as a result of careful design, construction and repeated tests to ensure uniform distribution patterns in still air conditions tend to rely on a variety of designs of long curved impellers attached to the surface of the disc, sometimes with alternation of impellers of different characteristics as regards length of throw. Only very carefully designed combinations used in strict accordance with the manufacturer's instructions and double overlapping of patterns can produce satisfactory results at very wide tramline distances.

Even with a good distributor which has a symmetrical distribution pattern, considerably more fertiliser is delivered over the central part of the bout than at the edges. It is therefore necessary to study the distribution pattern carefully, and to seek the manufacturer's guidance on the necessary amount of overlapping. It is impossible to do good work with a distributor that has a very asymmetric distribution pattern.

Some of the earliest spinning disc machines used two contra-rotating discs, but were not renowned for their evenness of distribution. With careful setting a modern machine fitted with two discs can do very good work, any one-sided effect due to the action of the disc itself tending to be counter-balanced by the other disc. One of the main advantages of drill tramline systems is that it provides a reliable bout-marking procedure for spraying and fertiliser distribution; and for large-scale work there are advantages in wide tramline bout widths (e.g. 12 m or more). Because of such factors as wind and slope, pneumatic distributors with wide booms tend to give a more even pattern than spinning discs or similar types at wide bout widths. A disadvantage which can be serious on soft wet land is that the pneumatic delivery type is often quite heavy. At intermediate widths the simpler types can be satisfactory if well designed and sensibly used; some twin-disc types can give a more even pattern than single; and a combination on each disc of long and

short vanes can help by flattening the spread pattern. It is, however, advisable with all spinning disc machines to operate at a fairly wide overlap; for example, a machine working in 12 m tramlines typically needs to provide a double overlap by working along every tramline at a spread width with a measurable amount delivered to 24 m width. It is necessary to be able to spread to one side only to ensure full application rate up to field edges but not beyond.

With wide-bout twin-disc distributors it is useful to have an in-cab hydraulic control to a three-way valve which operates the flow gates to both discs independently and immediately. This can be used to provide application at full rate on one side only.

Pto speed has a marked effect on bout width; and every precaution should be taken to avoid unnecessary variations, especially with spinning disc machines used on very wide tramlines at less than double overlap. An in-cab pto speed monitor with warning lights can be a worthwhile fitting for spreading work on gradients.

Spinning disc distributors may be tractor-mounted, trailed or, rarely, mounted at the rear of a truck. With long trailer or truck-mounted machines designed for bulk handling it is essential to have a positive means of transporting fertiliser on to the disc or discs. Endless rubber belts, chain and flight conveyors and augers are used. The conveyor chain can provide a relatively simple means of adjusting application rate; it may be land-wheel-driven for simplicity. Fluctuations in the set speed of the spinning discs must be avoided in order to keep effective bout width constant. Drive is usually from the pto, but hydraulic drive can be very effective. A flow control valve in the hydraulic system and a revolution counter make it possible to ensure that speed of rotation of the disc is kept constant. One type of electronic easy-to-use disc speed monitor is simply pointed at the spinning disc and provides a digital read-out (e.g. Lely). With high-speed mounted spinning disc machines the level of the discs above the ground or crop, and also their level from side-to-side and from front to rear, are affected by the linkage adjustments and need to be checked.

When a new material is to be distributed and the correct bout width is unknown, it is fairly easy to carry out a rough stationary check on the barn floor. The machine is driven at normal pto speed, and the amount delivered over each part of the bout is determined by sweeping up in equal strips parallel to the direction of

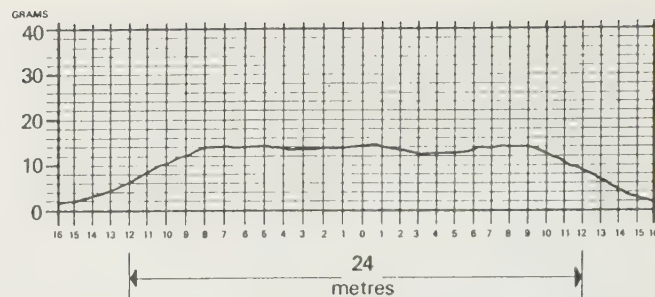


Fig. 8.9 Type of flat-top symmetrical spread pattern, with appreciable quantity delivered to 16 m on both sides, required from twin-disc spreader if used on a single pass over 24 m tramlines. Pattern is achievable by combination of high-speed discs each fitted with short adjustable vane for spreading close to the machine and longer vane mainly for edges of bout. Good results at this bout width require reasonably level land and little wind, as well as meticulous maintenance of speeds. (*Hestair Bettinson diagram*)

travel, and weighing the amounts collected. It is then possible to construct distribution patterns similar to that shown in Fig. 8.9. For example, if five successive 1 m strips swept up on one side of the centre-line give 10, 8, 5, 2.5 and 0.5 kg of fertiliser respectively, this indicates that if a 5 m bout width is used to give a complete overlap, the total amounts spread on successive strips will be 10 + 0.5, 8 + 2.5, 5 + 5, 2.5 + 8 and 0.5 + 10 kg respectively. This would provide a fairly even distribution.

Unevenness is most often caused by using too high a sowing rate and too great a bout width. This will almost inevitably result in over-dressed strips coinciding with the centre-line of the distributor, and under-dressed strips in between. Recommended bout widths are usually lower for granular fertiliser, than for prilled.

Oscillating spout delivery

One simple type of delivery mechanism that will deal effectively with most fertilisers consists essentially of a tapered spout, which oscillates fairly rapidly and throws out the fertiliser in much the same way as a man does when broadcasting by hand. The swath covered is quite often less than 10 m wide and the transverse distribution pattern is much flatter than that given by spinning disc machines.

It is therefore necessary to take particular care to get bout width correct for the material used.

Pneumatic distributors

'Pneumatic' distributors are provided with evenly-spaced outlets and designed to operate as 'full-width' machines, with a level distribution pattern and a sharp cut-off at the edges. They are ideally suited to work such as late applications of nitrogen to tramlined cereals, provided that the bout width is correct. Air speed along the tubes is commonly about 30 m/sec, and power needed to drive the fan about 0.3 kW per line. The granules impinge on curved stationary plates to provide an even spread and reduction of speed. Hopper capacities on mounted machines are usually limited to about 1 tonne, but capacities of 3 tonne or more are provided in a few very large trailed machines.

Some of the largest may cover bout widths beyond 12 m, but this may sometimes be achieved by special jets at the expense of the typical flat delivery pattern.

Assessment of evenness of distribution

A study carried out by ADAS on 177 machines of 18 makes in practical use on farms in 1980 was facilitated by use of a specially prepared computer programme to analyse evenness of distribution on each farm. It showed that it was possible with most machines to achieve a coefficient of variation of 20% or lower, but that half of the machines assessed were above this barely satisfactory performance measure (10 to 15% coefficient of variation (C of V) is reckoned a reasonable aim).

Reasons for the bad performances were of easily understood kinds: e.g. spinning disc types operated at too wide bout widths or producing asymmetric patterns; oscillating spouts needing new parts or used at unsuitable bout widths; and too little attention paid to height and angle of both of these types. The full-width pneumatic type suffered from inaccurate joins between adjacent bouts — a fault which should be much less frequent now that adoption of suitable tramlining practices almost invariably accompanies use of this type. The importance of attention to detail is illustrated by comparison of performance of two identical 12 m distributors of this type used by different farmers. A machine working near its best showed a good 10% C of V. On another farm the result of a combination of mechanical faults and areas missed between bouts was very unsatisfactory at 24% C of V.

Accuracy of distribution by pneumatic distributors with wide booms naturally depends on maintenance of the outlets at uniform height, and an absence of appreciable yawing. The benefits of isolation of wide sprayer booms from the vehicle chassis by means of a well designed suspension system with suitable linkages and dampers are briefly discussed in Chapter 9.

Lime spreaders

Machines designed specially for lime spreading usually have a long V-shaped hopper with a conveyor, often a rubber belt, running along the bottom and delivering to a spinning disc or a pair of discs at the rear. The best of these machines may be used for distributing fertilisers, provided they are maintained in good condition. An effective service is often provided by contractors' four-wheel-drive road vehicles with spreader bodies which run direct from sources of supply on to the land.

Combined grain and fertiliser drills

The practice of drilling corn and fertiliser together down the same coulter in combined grain and fertiliser drills became established when experiments, carried out mainly on land very deficient in fertilisers, showed that a given quantity of the commonly used fertilisers produced appreciably higher yields when combine-drilled than when broadcast on the seedbed. This applied particularly to the use of phosphatic fertilisers on land with an acute phosphate deficiency. In recent years, the fertiliser status of most corn-growing soils has been built up to a point where there is no such acute deficiency. In these conditions, the difference in favour of combine drilling has become small, and other factors such as inter-row spacing are of comparable importance. Other factors tending to cause some farmers to revert to using plain corn drills are the possibility of spreading the fertiliser easily using bulk-handling methods, and the desire to get the drilling operation completed quickly, without the hindrance of combined fertiliser application.

In spite of such developments, there are still many farms where combine drilling is the most economic technique, especially where the combined dressing is a light one. Combine drilling is also preferable on some types of

heavy land, where it is essential to avoid unnecessary tractor wheelings arising from a separate operation.

The proportions of grain and seed needed per unit area can vary considerably, and for this reason manufacturers offer means of varying the size of the seed and fertiliser hoppers by changing the effective shape of the partition that divides them. This may be done by reversing top-to-bottom a dividing plate containing a U-shaped indentation along its length. One manufacturer uses a flexible partition which considerably increases the capacity of the side that is filled first. Where no fertiliser is needed it may be possible to remove the partition completely.

Combine drills normally sow seed and fertiliser down the same seed tube and coulter, but a few can be set to sow the two separately. There is a risk of damage to the seed corn if too high a concentration of soluble fertiliser is sown in contact with it. Generally speaking, phosphatic fertilisers are harmless, but potassic salts, such as muriate, are liable to delay germination and burn the young roots. Nitrogenous fertilisers are intermediate between phosphatic and potassic in this respect, and root crops are more susceptible than cereals. Damage is most likely to occur in dry weather. Peas, beans and a number of horticultural crops, on the other hand, respond best to 'side-band placement' of the fertiliser; for these, experiments indicate that the fertiliser should be placed about 50 mm (2 in) to the side and slightly below the level of the seed.



Fig. 8.10 A 4 m combine drill with 32 closely spaced coulters and direct-attached spring-tine coverers. The optional 24 coulters at 'conventional' spacing can suit heavy land better. (Richard Weston Bamlett)

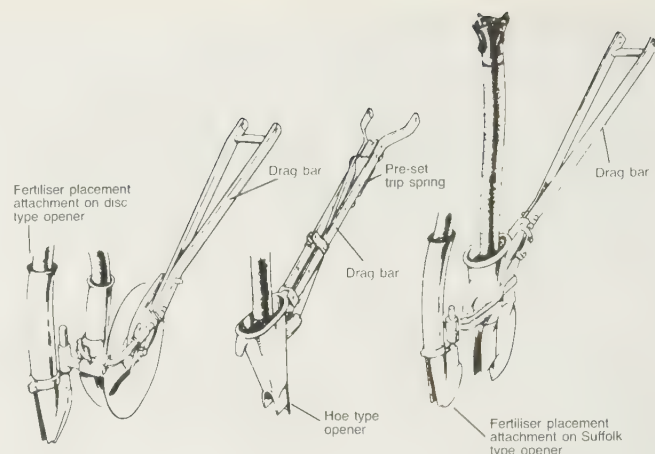


Fig. 8.11 Drill openers with fertiliser placement attachments. (Massey-Ferguson)

Kale and similar green forage crops usually need only small amounts of phosphate and potash, and these are best applied just below the seed, while the heavy dressing of nitrogenous fertiliser required is best applied later. There is usually no advantage from side-band placement of fertiliser for drilled grass, and the bulk of the fertiliser should be broad-cast. About 125 kg/ha (1 cwt per acre) of super-phosphate can, however, be drilled in contact with the seed and will help to promote rapid establishment in difficult conditions. With lucerne, a smaller 'starter' dose of super-phosphate can with advantage be drilled directly beneath the seed and about 25 mm (1 in) deeper.

Placement of fertiliser for spring barley about 90 mm (3½ in) deep by means of a tined distributor can in some conditions result in a higher yield than distributing the same quantity of fertiliser over the surface. This is because the surface layers of soil may be too dry in late spring and summer for broadcast fertiliser to be available to the crop plants.

An early type of fertiliser metering mechanism used on combine drills consists of a series of horizontal notched wheels, generally called 'star' wheels, each of which sweeps fertiliser from the hopper through an opening in the bottom leading to the seed tube. Research showed that with slow-running star wheels having only a few notches there were marked peaks in the distribution pattern at intervals corresponding with the action of the individual 'teeth'. This often caused severe scorching of spring-sown

crops. Improvement in performance was achieved by use of smaller notches and higher frequency of action. The star wheels may be made of rubber and used in conjunction with a rubber-coated hopper bottom to avoid corrosion problems. Many modern combine drills use metering mechanisms identical with those used for metering the seed — e.g. fluted rollers made of nylon or urethane, and studded rollers of various types.

Liquid fertiliser can be 'placed' when drilling or planting. Saddle tanks or a front-mounted tank are usually carried on the tractor. Adjustment of application rates may be facilitated by use of a land wheel-driven low-pressure peristaltic pump with an independent pipe system for each delivery point.

The combine drill is a complicated machine; unless it is well cared for, the whole drill may depreciate rapidly. It should be a rule, both with the combine drill and any other fertiliser distributor, to empty out the fertiliser every night, to cover the machine with a sheet and to give the whole machine a thorough clean with water as soon as sowing is completed.

The machine should then be taken to pieces, washed in hot dilute washing soda solution ($\frac{1}{2}$ lb to a gallon), dried and covered with a rust-preventive. When the machine is to be used again for the first time after long standing, it is advisable to make sure of avoiding any serious breakage due to corrosion by first turning the drive shaft with a hand wrench. This is particularly worthwhile if cleaning before storage was omitted.

Developments in seed and fertiliser tubes include the use of rubber, strengthened with an integral steel spring to provide a smooth, corrosion-resistant inside surface, having flexibility but resistant to kinking. The use of plastic tubes is likely to increase, and a hydraulic lifting mechanism which raises the seed box, seed tubes and coulters as a single unit helps to avoid failures due to repeated bending of the tubes.

Farmyard manure handling machinery

The return of animal manures to the land is an essential feature of the management of most British farms which are engaged in livestock production. In the past, the manure was usually some type of solid 'farmyard' manure made by adding straw or other absorbent bedding materials to the excreta; more recently, the need to

economise in labour has resulted in the development of stock housing systems in which a mixture of dung and urine or 'slurry' is handled in liquid or semi-liquid form, without deliberate admixture apart from a variable amount of water. Such systems have become important and are dealt with separately later. There are, however, many advantages in handling manure as a solid, provided that handling of both bedding and manure are well mechanised, especially on farms where large amounts of straw are available.

Front-mounted tractor loaders

Front-mounted tractor loaders are available in a variety of makes for fitting to any modern general-purpose tractor. These machines are normally operated by the tractor's built-in hydraulic lift pump, and their individual capabilities depend as much on the tractor as on the loader itself. The variables which need to be studied are manoeuvrability of the tractor in difficult ground conditions and in obstructed enclosures; ease of control of the lift and tip; height of lift; capacity of bucket; and power of the tractor's lift system. Loaders with a hydraulic ram to push the manure off the bucket on to the load are increasingly used.

Performance figures for one maker's general-purpose trip-beam loader with a lift capacity of 1 ton are 10%



Fig. 8.12 Front loader with manure bucket on four-wheel-drive tractor loading trailer spreader. (Case-International)



Fig. 8.13 Loading manure from field heap using articulated chassis heavy-duty loader with large grab incorporating push-off. (JCB 'Farm Master')

extra break-away capacity, a cycle time with full load of 10 sec and with no load $3\frac{1}{2}$ sec, and a maximum delivery height of 2.5 m (8 ft). A comparable 'power' loader has a slightly larger break-away capacity, but the main differences are (a) a 'crowding' action (about 25°) to provide for better filling of a bucket, and (b) rolling back and tipping by hydraulic power. Typical tipping angles for clean emptying are about 60° for bucket and 70° or more for a fork. Modern loaders must be capable of being fitted and used on a tractor that is complete with safety cab.

An important feature on many farms is ease of fitting and disconnecting the loader. On some machines this is facilitated by provision of support jacks which hold the loader ready for the tractor to drive into the frame. The frame is designed so that it automatically goes into place on the guides which remain on the tractor; all the driver has to do is lock the frame in position, connect up the hydraulic couplings, remove the support jacks, raise the loader and drive off. Hydraulic loaders are simple machines, and if carefully used they have a long life. The first cost is moderate, and the loader can be used for a

variety of other jobs, especially if a range of fittings, e.g. root bucket, etc., is provided.

It is an advantage to have removable partition supports which fit into sockets in the yard bottom. The loader should work on the yard bottom, which should be kept as free from spilled muck as possible, to reduce wheel spin. Wheel spin which results in damage to tyres and yard surface, and in loss of manoeuvrability, is reduced by adding weight to the rear of the tractor. Added weight also improves stability.

Manure should be pulled off the top in layers, and the forkfuls built into a load on the spreader, not merely tipped in the middle of it. On rear-delivery spreaders, it is best to start building the load at the front end.

Rough-terrain fork-lift loaders

Many types of rough-terrain fork-lift vehicles designed for agricultural work have manure-loading as one of their important applications. The vehicles themselves are more fully considered in Chapter 21. With a typical medium-powered vehicle, fork-loads of over 1 tonne can be quickly extracted from yard or heap and transferred to transport or spreading vehicles. Very large forkfuls of 'long' or very dense manure can, of course, provide distribution problems for some types of spreader mechanisms.

Mechanical gutter-cleaners

Several types of electrically operated gutter-cleaner are now employed on British farms, and their use is likely to extend considerably. In the first type (e.g. Alfa-Laval) a winch-operated scoop is dragged from the far end of the building and may tip into a trailer or spreader which stands in a sunken road just outside the building, or push the slurry into a below-ground duct or reservoir. This system is successfully used for all types of stock. In the case of piggeries, the doors to the dunging passage are closed before operation. With poultry, the dunging pit is normally covered by slats and so is inaccessible to the birds. In the usual layout two dunging passages or pits are cleared by two scoops, interconnected by means of a single cable which runs round grooved idler pulleys at each end of both gutters, and is operated by a single drive unit with an automatic reversing mechanism. As one scoop is pulled forwards the other returns to the far end of the building. A typical unit uses a 0.6 kW ($\frac{3}{4}$ hp)



Fig. 8.14 The tractor-mounted multi-purpose slew loader can be used for loading silage or manure without unhitching. (McConnel)

motor which pulls the scraper at 11 ft/min (3.25 m/min). The V-shaped wings of the scraper fold on the way back. Passage widths scraped can be from 0.8 to 3.2 m.

A second type, designed for cowsheds, has slats attached to an endless chain which runs up one gutter and down a second. It runs round the building and then drops the manure after rising up an incline at a convenient point at one end of the building (Fig. 8.15). Each type mentioned has advantages for particular building layouts and conditions.

Another method of cleaning cowsheds is to have a single wide gutter designed to be cleaned by running a tractor and mounted scraper along it. At the end of the run the manure may be pushed either into a pit or up a gentle incline for dropping into a vehicle.

A handy type of slurry scraper is rear-mounted on the three point linkage and is equipped either with reversible

wings or with wings projecting both to front and rear. The latter type can be used either to push or pull the slurry without the necessity of making any adjustment.

There is little doubt that one of the most labour-saving methods of cleaning cow housing is use of a slatted floor and cubicle system. Success requires good design of cubicles, slats and general layout, and management which takes account of the problems involved in cleaning out the pit beneath the slats. Desirable features of cubicles include sufficient length to allow the cows to lie full length, but with a cross bar to make it uncomfortable to stand forward in the cubicle; and a dished shape which helps to prevent bedding being pushed on to the slats.

Fully slatted pens can also be used successfully for pigs, though solid floors and a slatted dunging passage are more usual. One method employed to clean a solid-floored dunging passage is use of a slow-speed endless



Fig. 8.15 Automatic 'Delta' type winch-operated scraper cleaning a cubicle house. (*Alfa-Laval*)



Fig. 8.16 Large capacity farmyard manure/slurry spreader (7250 l, approximately 8 tonnes) with double-taper centre feed auger and wide spreader door designed to secure high discharge rate at low power requirement. The door can be closed down by the single hydraulic ram to reduce application rate; for slurry a narrow door opening can be selected over the full width of the impeller. Deflector plates secure a spread width of approximately 12 m. (*ECON Powerspread 725*)

chain and slat scraper which returns at a level just above the pen divisions.

Endless chain and slat cleaners are widely used for laying batteries, but an alternative is an endless plastic belt. Such battery cleaners may be operated by a press-button system or by time clock.



Fig. 8.17 Side-spreader of all-welded rolled steel drum construction with wide hydraulically operated large lid, making it suitable for loading by large bucket or fork. Top-of-range model shown has capacity 6.7 m³ (8.8 yd³), one-piece forged flail head plates and range of rotor drive sprockets to assist matching to power of tractor used. (*Dowdeswell 2070*)

Trailer spreaders

A long-established type consists of a low wagon with a travelling bed which carries the load of manure slowly and uniformly towards revolving beaters at the rear of the machine. The beaters tear the manure into small fragments, and an additional cylinder scatters it over a strip wider than the machine. A suitable factor for estimation of load carried is 0.85 m³ (30 ft³) of truck capacity per ton.

In some machines the final spreading is carried out by a flail-type beater which is well balanced, and designed to rotate at a high speed. This type of mechanism can produce a thorough pulverisation but requires more power than one with a low-speed main beater shaft e.g. 600–700 rpm. Where chains are used they need to be designed to withstand heavy loads in conditions which make good maintenance almost impossible. Drive to the conveyor is usually by an easily adjusted ratchet mechanism, the rate of spread being varied by adjusting the throw of a rocker arm. Spreading rates can usually be varied from about 7500–50 000 kg/ha (3 to 20 tons per acre).

The flail-type side-spreader with a long, semi-cylindrical tank, has a pto-driven shaft running along its axis. A number of chains attached to the shaft rotate at a fairly



Fig. 8.18 Flail manure spreader with hydraulically controlled rear end-gate attachment to permit handling thick slurry. (S.K.H.)

high speed and gradually extend as they work into the load from both ends. The main advantage of such a machine is its simplicity and its ability to handle very wet materials (Fig. 8.19).

Achievement of good results with side-distributing flail



Fig. 8.19 Rotary flail side-spreader with 'original' A-frame chassis construction, capacity 4.2 m³ (5.5 yd³) (Model 1552 Howard Rotaspreader)

spreaders requires skill and judgement on the part of operators. Filling should begin by putting forkfuls beyond the rotor. If the loader and spreader are operated by separate tractors, the pto-drive of the spreader tractor should be slowly engaged when the machine is half full, to settle the bottom of the load and to wind the chains round the rotor. The ends of the rotor should be only lightly loaded.

Spreading rate is governed by tractor throttle setting and forward speed. If uniform speeds are used throughout, spreading will not be uniform, because when the spreader is two-thirds empty, many flails are operating effectively and spreading rate tends to be higher. At this point, therefore, it is necessary either to reduce throttle setting or change to a higher gear. The operator needs to use his judgement continuously to decide what forward speed and throttle setting are required. Bout width is usually about 10 ft (3 m).

One design of cylindrical side-spreader (e.g. Hillam) has the body supported on carrier rollers so that the opening can be rotated 45° either way by a hydraulic control. This provides for filling from either side; for transport of liquids with the opening at the top, and for variation of the angle during spreading to assist in obtaining a uniform dressing.

Dual-purpose spreaders

Developments include machines designed to handle both solid manure and slurries. A successful type employs a hopper with a U-shaped bottom, and a full-length flighted rotary horizontal conveyor running near the bottom to carry manure forward to a variable-width opening on one side near the front. When the opening is fully closed by a hydraulically operated sliding gate, the tank can be reasonably water-tight. The manure is pushed through the controllable gate to a high-speed impeller with axis parallel to the auger-type main conveyor and the direction of travel. A spring-loaded flap can protect the impeller from damage by large foreign objects in the manure: additional over-load protection is provided in the main drive.

A well distributed, wide swath limits soil damage by wheel tracks. The forward-moving load helps to maintain tractor wheel adhesion (e.g. West 'Dual-spreader', Econ Atkinson 'Powerspread', Kidd 'Tanka-spread' with a range of three sizes).



Fig. 8.20 Dual-purpose spreader with flighted conveyor and hydraulically operated sliding gate separating main tank from the high-speed impeller. The machine shown spreading solid manure can also handle slurry. (Kidd 'Tanka-spread')

Manure-handling systems

The operation of getting manure from yards on to the land may be split up, either by choice or due to the necessities of husbandry, into a number of distinct stages. For example, the fact that yards often have to be cleared during slack periods in summer when the land is growing crops, or in winter, when fields are too wet for transport, may necessitate making field clamps, regardless of whether this fits in with a preferred manure-handling system or not. Spreading directly from where the manure is made is usually advantageous when it is practicable, both on account of economy in labour and also in regard to avoiding unnecessary loss of nutrients. On the other hand it often does not fit in with the necessities of farm management, so the making of field clamps must continue to be a frequent requirement. Some systems of operation are clearly preferable for particular circumstances on account of economy in expenditure on specialised equipment, or the efficient use of labour, or for both reasons. Occasionally, however, the requirements of farm management make it necessary to employ large gangs which will get the job done quickly, and this may justify a high capital investment in equipment. There is, of course, no justification for a high investment and use of a large gang unless the operations are properly balanced to produce a high rate of work. Contract work is often worth study.

Operating with a small gang

One of the most efficient manure-handling systems, both as regards minimum capital investment and labour economy, is the 'one-man' system whereby the man, equipped with one tractor and either a front-mounted loader and an easily hitched trailer spreader, or with more capital involved, by leaving a separate loading vehicle at the loading point. With a transport distance of 0.4 km ($\frac{1}{4}$ mile), about 6–10 tons per hour can be loaded and spread. There is nothing in this job to make the man tired, and if he works steadily he can deal with a large quantity of manure in a few days. Similarly, a one-man outfit consisting of tractor, loader and hydraulic tipping trailer can clear yards and cart to a field clamp at a reasonable rate, doing any necessary tidying-up at the clamp with the loader.

For direct spreading, a two-man gang consisting of one loader and one spreader is wasteful of labour, but two men can work efficiently with two spreaders or at transporting manure from yards to clamp, using one loader and two trailers. The second man can help in building good loads. A better arrangement, however, is to have a third tractor equipped with the loader, each spreader driver working independently and using it in turn.

Larger gangs and long hauls

For high-speed loading and spreading on short hauls, e.g. when spreading from a field heap, a three-man gang using one loader and two spreaders can be fairly efficient. This system is unbalanced if the transport distance is appreciable. The spreader driver cannot do much to help during loading, but it is worthwhile with a pto machine to engage the pto drive after a few forkfuls have been placed in the back of the box, so that full spreading rate is immediately attained when the power drive is engaged in the field. When this is done, the spreader should be systematically loaded from the rear, i.e. the reverse of recommended practice with a wheel-driven machine, where the object of loading from the front is to avoid overloading the drive mechanisms at the beginning of unloading.

When carting to a field clamp the remedy for long hauls may be to introduce more transport vehicles, but few farms can justify a fleet of mechanical spreaders, and where direct spreading on long hauls is needed some

other system of operation which does not call for continuous loading is necessary. This is quite easy to devise; for example, by cutting down the number of men to two, the spreaders can make their journey together and the two men can together operate a loader at the yard. Alternatively, the two spreaders can work well apart, and their drivers can operate a hydraulic loader mounted on a tractor which stays at the yard.

Sufficient has been written to indicate the importance of giving considerable thought to proposed handling systems before deciding what equipment to buy. Mechanical spreaders are far from ideal machines from a maintenance standpoint, and their rate of operation when actually spreading is so high that there can seldom be much justification for having a fleet of them for carting manure along the road.

Distribution of slurry

Where stock are kept wholly in strawyards or in other buildings which are well littered, the dung and urine are absorbed by the bedding, and though some of the manurial constituents may be lost at various stages of storage and application, mechanical handling is fairly simple, and there need be no serious problems as regards pollution of streams. Many modern methods of stock tending, however, are based on absence of bedding, and it may then

be necessary to handle the dung and urine in a liquid or semi-liquid form. One of the potential advantages of handling manures in liquid form is that it may be possible to conserve more of the fertiliser constituents, especially the nitrogen.

Slurries consisting of undiluted dung and urine, with some evaporation, and often with the addition of fibrous feeding-stuffs such as hay or silage, cannot be effectively handled without some dilution either by most tank spreaders or by irrigation systems. For handling through piped systems the minimum dilution required is normally about 3:1, though some pumps and rainers can dispose of material diluted only 1:1. Some types of tank spreader will effectively handle material with a dilution of less than 1:1, but in the absence of thorough stirring there is often difficulty in making such material enter a suction hose.

Most thick slurries need some mixing before they can be handled effectively by either vacuum-filled or pump filled tankers. One of the main mixing methods is to recirculate through a shaft-operated centrifugal pump which is lowered into the tank or installed in a sump through which the tank contents can be circulated. This and other similar types of slurry pump may incorporate a chopping mechanism to make fibrous materials more pumpable, but use of such equipment does not remove a need to exclude, as far as practicable, hay, silage, straw and twine. Where scraped slurry is likely to include such

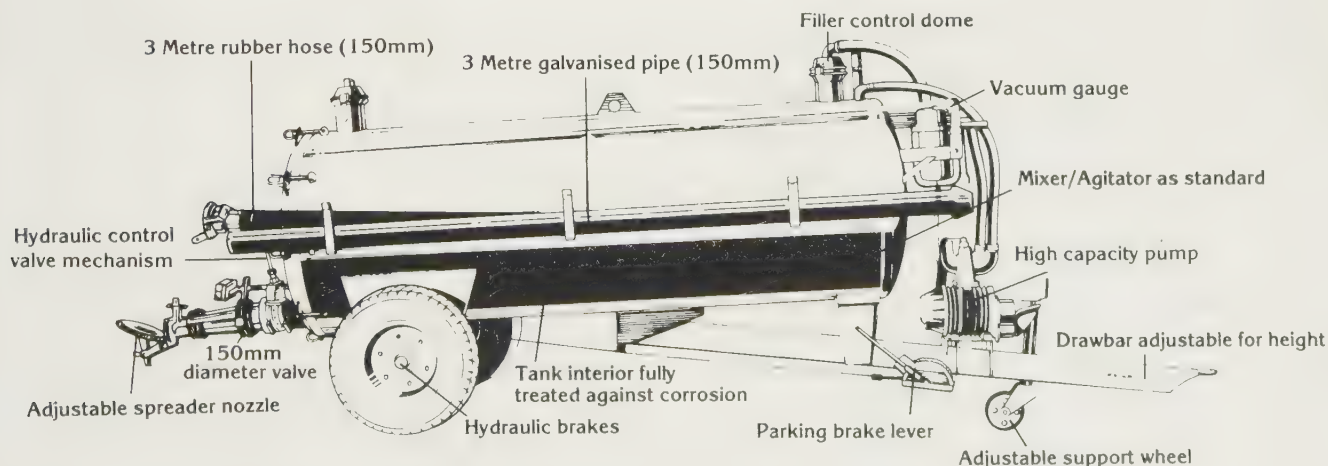


Fig. 8.21 Main features of vacuum-fill, pressure-empty slurry distributor.

materials it is advisable to strain it through a coarse grating at or near to the storage tank.

Work by the MAFF Experimental Husbandry Farms has shown that moderate applications of cow, pig or poultry slurries can save considerable cost on fertilisers, but excessive dressings can produce adverse effects.

Slurry tankers

The *Vacuum-fill pressure-discharge* type can work effectively with any other equipment provided that the slurry is a free-flowing liquid. Basic requirements include a well designed tank, a powerful vacuum pump, reliable regulator, inlet hose of ample size, and spreading arrangement to suit individual needs. Because of atmospheric pollution considerations, types that throw small particles long distances are unsuitable for use near residential areas.

The *gravity-fill mechanical-discharge* type can handle thick slurries provided that they can be delivered into the tank, either by gravity or by an independent slurry pump or loader.

The integral *pump-fill, pump-discharge* type can use its built-in pump to do any necessary mixing before loading, and can also pump slurry a considerable distance along pipes to a portable slurry gun for distribution if required.

Dribble Bars: Equipment for an effective system of slurry handling and surface application for normal agricultural purposes is illustrated in Fig. 8.22. Tanker model sizes range from 5000 to 9000 litres, all fitted with tandem axles, flotation tyres and hydraulic brakes. A positive-displacement pump can be chosen to suit slurry mixing, tanker filling and application needs.

The Dribble-bar Applicator, of 5 m standard width, is hydraulically folded for transport, with control from the driver's seat. Application outputs up to 1.8 m³ (400 gallons) per minute can be provided. With a well chosen pump and adherence to recommended storage, treatment and handling practices, fairly thick slurries can be handled with effective placement of nutrients for utilisation by crop, and minimal atmospheric pollution.

Where needed, a robust spring-back *soil injector unit* can replace the dribble bar and place the slurry beneath the soil surface: provision is made on the basic tanker for



Fig. 8.22 Multi-purpose 7000 l slurry handling tanker shown with 5 m dribble bar applicator hydraulically folded ready for transport (BKW Engineering)

a 'hydrotronic' drive hydraulic motor to be fitted to each of the four tanker wheels, with use synchronised with the appropriate tractor gears and forward land speed.

The BKW tanker-mounted injector details appear outstandingly well chosen and designed to suit the likely needs of medium-sized mixed farms in addition to those of specialist livestock farms. Good features include the sturdy but slim design of leg and share; a sound auto-reset spring release mechanism well suited to use in a reasonably wide range of soils; and a simple type of positive-displacement eccentric rotor pump which has a well proved record of thick slurry handling capability (see Fig. 8.23).

Slurry injectors

Slurry injectors have hitherto been most widely used on light-land arable soils in countries such as Denmark. Attractions of the system are avoidance of both atmospheric and run-off pollution, and effective utilisation of nutrients contained in the manure. The main disadvantages are that the work needs a strong tool-bar and a powerful tractor, and can only be carried out in a limited range of soil and crop conditions.

In Britain, development effort has been mainly on equipment suitable for contract use. In a tractor-powered

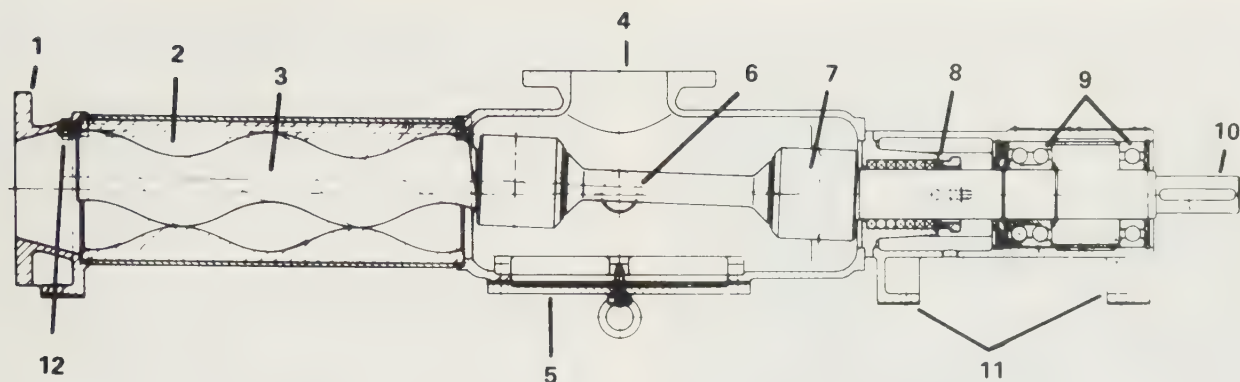
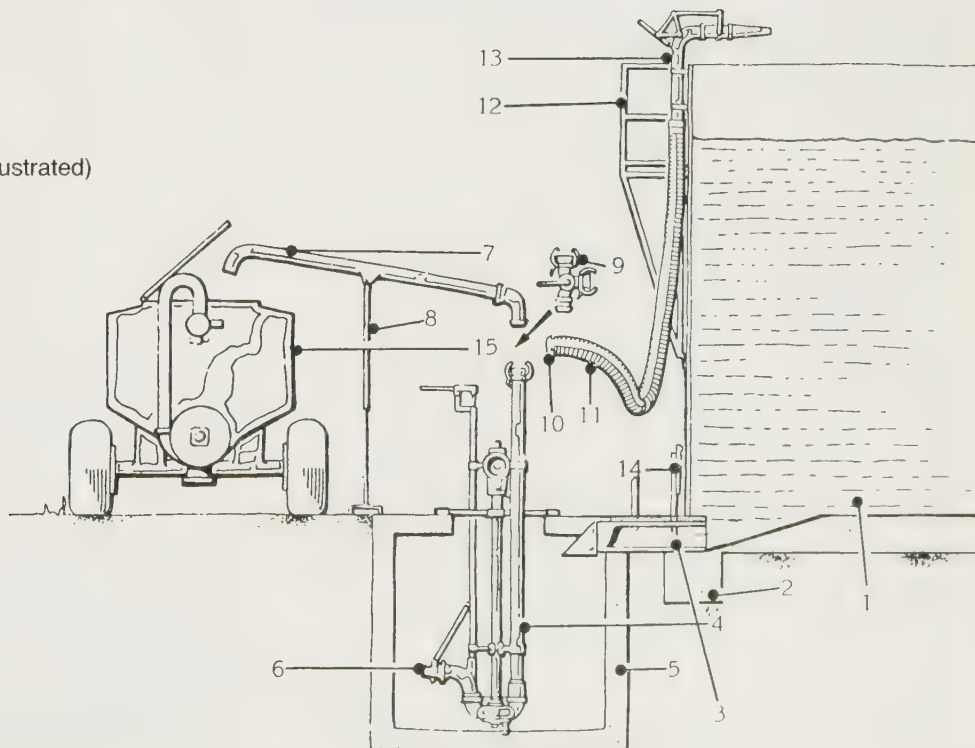


Fig. 8.23 Eccentric helical rotor pump used on pump-filled and -emptied slurry tanker. (*Farrow*)

1 Discharge flange, 2 Stator bonded to casing, 3 Rotor, 4 Suction inlet, 8 Gland, 10 Drive shaft.

Fig. 8.24 Diagram showing main features of typical above-ground slurry store with reception pit, tractor-operated pump with single nozzle jetter unit and spring-supported spreader filler pipe. (*Boythorpe*)

- 1 Slurry storage tank
- 2 Concrete foundation
- 3 Sluiceway
- 4 Slurry pump (PTO driven model illustrated)
- 5 Reception pit
- 6 Agitation nozzle
- 7 Spreader filler pipe
- 8 Spring support
- 9 Three-way valve
- 10 Male coupling
- 11 Flexible hose
- 12 Operators safety platform
- 13 Single nozzle jetter unit
- 14 Sluice control lever
- 15 Slurry spreader



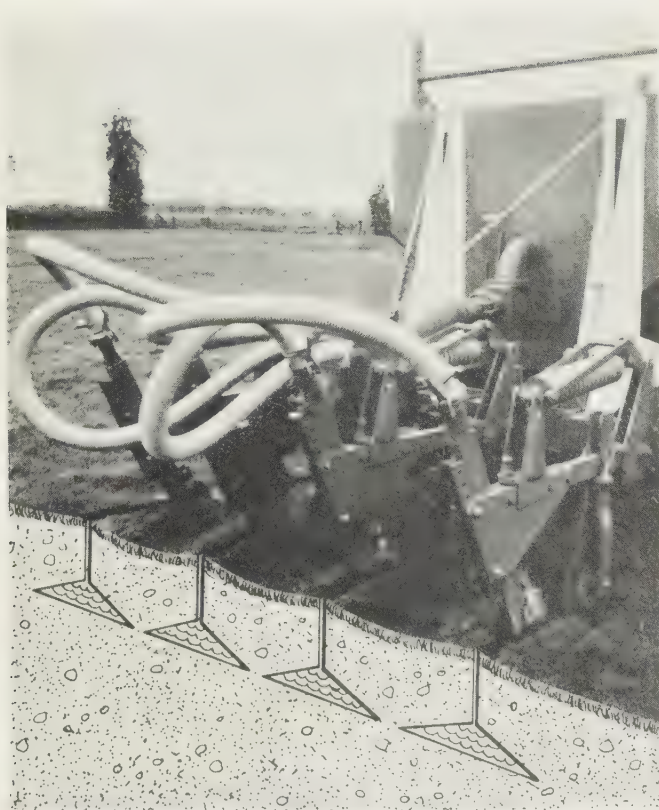


Fig. 8.25 Slurry tanker with injectors working in grassland. Diagrammatic section indicates 'broad-share' tine effect. (Wright Rain/Farrow)

system the tanker is equipped with large traction wheels powered from a 540 rpm pto with hydraulic engagement and overrun facility. A gearbox on the tanker provides a choice of gears to match practicable forward speeds. A suitable modified three- or four-leg Paraplow (Chapter 5) is attached by three-point linkage to the rear, and slurry is fed via adjustable gate valves to openings immediately behind the inclined legs (e.g. Weston 'Traction Drive'). A high-powered self-propelled tanker vehicle has hydrostatic transmission and four-wheel-drive by large traction wheels with articulated steering. Five rear-mounted tines can be vibrated to assist effective below-ground loosening without destroying crops such as permanent grass (e.g. Twose 'Vibraject').

Pipeline distribution systems: When slurry treatment results in production of a liquid that is easily handled by

ordinary irrigation equipment, a pipeline distribution system with semi-automatic moving is attractive. Final distribution systems include the hose reel type with wheeled boom which may carry low-level plate type distributors. A typical example with a 20 m boom has 220 m of 90 mm hose.

Equipment for slurry treatment

The main treatment processes that may be needed on farms are separation of solids, and aeration.

Slurry separators

Coarse solids can be separated by screening, use of a centrifuge or settling. Slurries can be partially separated into solid and liquid components either in-silo over a long storage period by use of suitably perforated silo walls or by a mechanical separator, normally operated from an intermediate holding pit on a daily basis. Reasons for and against mechanical separation systems need careful consideration (see list of references).

Many separation systems have been tried, but few fully satisfy all of the normal criteria for adoption, e.g. effectiveness, reliability, durability and reasonable capital, installation and operating costs. The main successful types employ soft but durable pressure rollers to force the liquid fraction through circular holes in stainless steel screens, with removal of solids from the screens by brushing and/or scraping. Two-stage systems are preferable where the objective is a stackable solid with dry matter content of 20%.

Rotary screen types usually employ soft rubber compression rollers on the outside of the cylinders, with hard rubber-covered rollers providing support on the inside. Diameter of holes in the screen may be about 3.2 mm ($\frac{1}{8}$ in) for cow slurry and 1.6 mm ($\frac{1}{16}$ in) for pig slurry. A tensioned scraper blade is used for solids removal.

In a dual-stage *stationary screen* type, pressure rollers provide multiple squeezing, and nylon brushes sweep the solids first to the second screen and then out of the machine.

Neither vibrating screens nor centrifuges can produce stackable high dry-matter solids from normal agricultural slurries economically.

Slurry aeration equipment

One of the established methods of treating effluents, to purify and reduce odour, is by aeration. The process is usually best applied to liquids from which the coarse solids have already been removed. Methods of carrying

out aeration vary greatly. The engineering problem is to provide a large surface of contact between air and the liquid, and this usually requires use of a compressor and nozzles to produce many small bubbles; some stirring of the liquid is also often necessary. One simple type with a low power requirement (e.g. 3 hp) has automatically

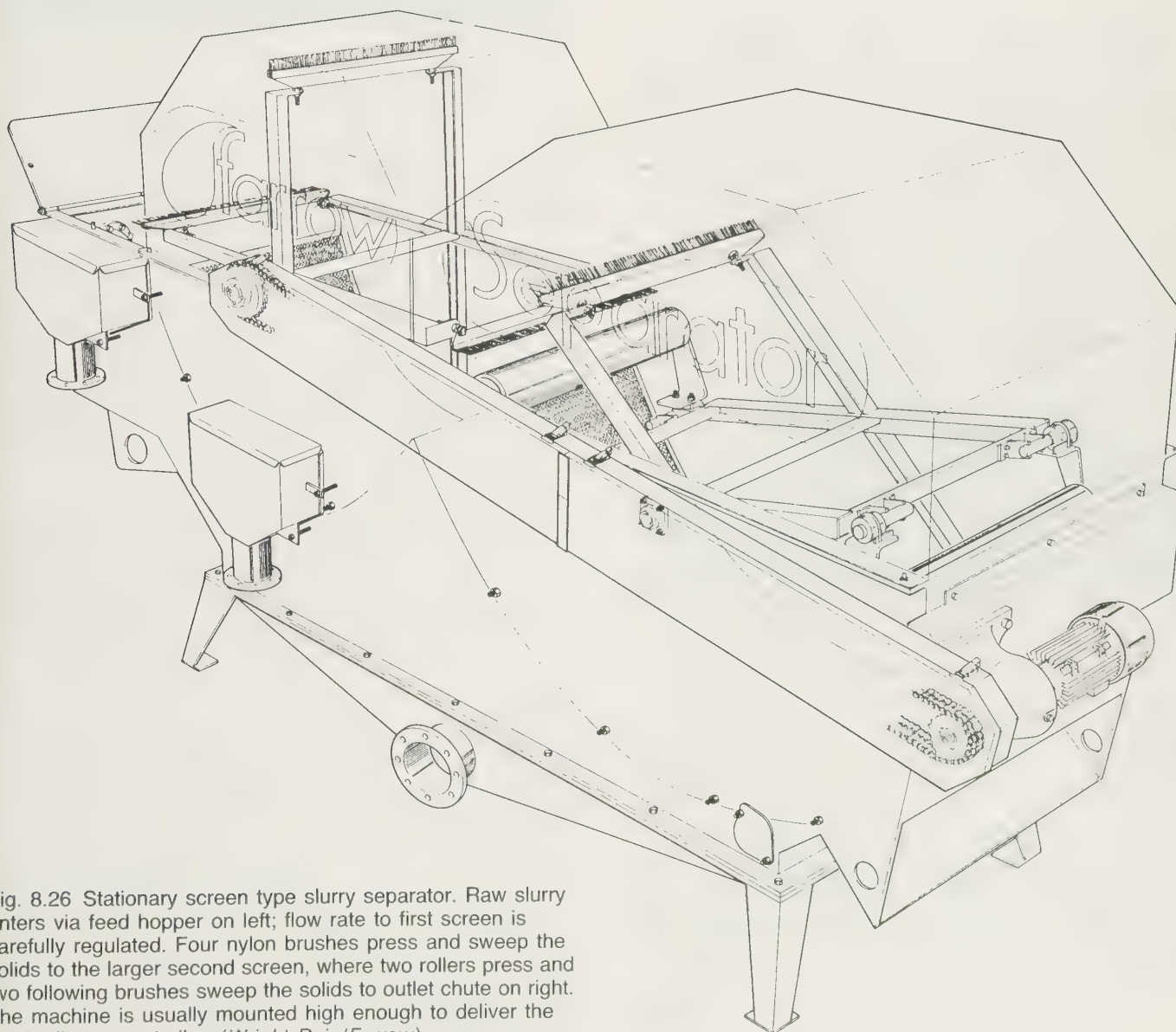


Fig. 8.26 Stationary screen type slurry separator. Raw slurry enters via feed hopper on left; flow rate to first screen is carefully regulated. Four nylon brushes press and sweep the solids to the larger second screen, where two rollers press and two following brushes sweep the solids to outlet chute on right. The machine is usually mounted high enough to deliver the solids direct to a trailer. (Wright Rain/Farrow)

operated valves which direct compressed air in turn to a number of different sets of nozzles suitably located in the storage tank to ensure that all areas are effectively aerated in succession. In a typical example where the main objective is reduction of smell when spreading, a time-clock may be used to operate a number of solenoid valves in succession in order to aerate and stir the slurry effectively in all parts of a large tank. Use of the equipment in a suitably selected period at night saves power cost and is least likely to cause complaints in a residential area.

With cow slurry stored in a large tank, a case can be made for reliance on a naturally formed thick surface crust to minimise atmospheric pollution during most of the long slurry accumulation period; a tractor-operated impeller can then be used just before emptying.

Bacterial activity resulting from intensive aeration of little-diluted slurries is a heat-producing process capable of maintaining a lagoon temperature of about 35°C in average UK temperatures; but the capital expenditure on heat pumps etc. and the high level of design and management needed to convert a potential for energy saving into an economic farm installation makes rapid adoption of such processes unlikely.

Electrically operated venturi agitators

For large-capacity slurry stores of good open top cylindrical tank type, e.g. one with 1000 m³ (220 000 gal) capacity, a 7.5 kW unit which combines the functions of aeration for odour control, thorough mixing before spreading and simplified slurry loading can be worth study. The Maguire VO2 is such an aerator designed for fitting to new or existing above-ground slurry stores. Only the Venturi barrel extends into the tank, and it is directed downwards at an angle of about 15° from about 1 m above tank bottom level, and in plan about 45° to a diameter line from the inlet to provide effective rotation for mixing purposes. Controls necessary to get the best from a new installation include a valve to the pump inlet and two more to isolate the venturi action when an elevated tanker loading outlet is to be used. An electrical starter control box with adjustable timer for restricted off-peak operation is essential for economic use, and to facilitate limiting aeration time to the dark hours of early morning if necessary.

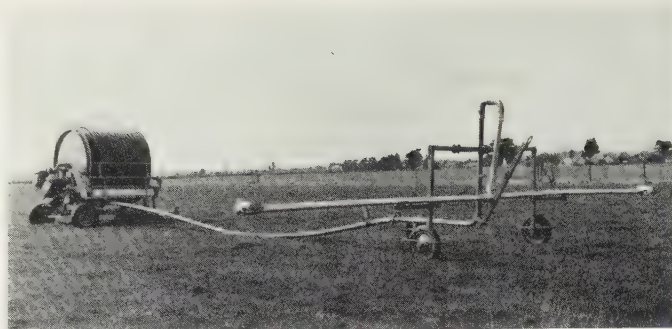


Fig. 8.27 Hose reel with tricycle slurry boom using low-angle splash plates. (Wright Rain)

Anaerobic digestion with methane gas production

A treatment method with energy-saving potential for intensive pig and poultry units is anaerobic digestion, involving the production and utilisation of methane gas. High capital costs are involved, and about half of the methane produced by a small plant in winter in the British climate is needed to keep the digester at the best temperature: but the success of the process in municipal sewage installations, and results already achieved by prototypes at official research stations and on commercial farms indicate that the process could be economic in large-scale (e.g. 2000 capacity) pig units.

The day-to-day engineering management tasks have been found in practice to be well taken care of by automatic controls. The main problem restricting development is the economic one of finding profitable use for the surplus heat energy that can result where high dry matter slurry is produced by the livestock husbandry system.

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Equipment for Crop Protection

Crop spraying

As the application of science to farming progresses, spraying is employed for an ever-widening variety of purposes. The chief 'crop protection' operations are the application of herbicides to reduce the competition from weeds; protective fungicides to minimise the effects of fungal diseases; insecticides to control various kinds of insect pests, and hormones to regulate crop growth. In addition, spraying is employed for the application of micro-nutrients such as manganese or boron, for burning off excessive 'flag' on cereal crops in order to reduce the danger of lodging, and for destroying potato haulm before mechanical harvesting equipment is used. For effective control of many insects 'systemic' sprays which are translocated within the crop plant provide the most effective remedy. The economic advantages of such operations as spraying for weed control are experienced in the form of increased yields and in future benefits due to prevention of seeding. In this, as in most other crop protection operations such as spraying with fungicide against potato blight, benefits are inversely proportional to the degree of infestation present or impending.

The increasing scope for use of chemical herbicides is well illustrated by the results of experimental work on potato cultivation. Here, the absence of cultivations can lead to two kinds of benefit: increased yield, owing to avoidance of root damage to crop plants and loss of soil moisture, and easier harvesting due to having avoided cultivation at times when clods would be formed by tractor wheels running on moist soil.

Use of the main types of herbicide may be illustrated by reference to potato cultivation. Contact herbicides are used when weeds have begun to grow but before the potatoes have emerged. They vary in selectivity. Residual herbicides must be applied before the weeds germinate,

and in such a way that the crop plants are not affected. This usually means a very carefully applied surface application to a soil which has been worked to a fine tilth. Safe rate for potatoes is often no more than 0.56 kg/ha ($\frac{1}{2}$ lb per acre) of active ingredient, so very great care



Fig. 9.1 Medium capacity model from modern tractor-rear-mounted sprayer range fitted with 12 m manually folded hydraulic raise/lower boom. (ALLMAN ACE range) Features include short and wide saddle-shape moulded tank with central strengthening tunnel providing direct run for linkage to boom and neat routing of pipes from controls to nozzles. External cylindrical chemical inductor vessel (right); and built-in clean water tank (top left). Usual control system for model suited to tractor of 52 kW (70 hp) is manually operated and incorporates automatic proportional flow regulator effective over minor speed variations in same tractor gear. Diaphragm pump located for accessibility and flooded suction: stainless steel spray lines; 110° colour coded nozzle tips in self-aligning caps at 500 mm spacing. Larger models in range incorporate electro-hydraulic boom folding, solenoid-operated boom selection valves and options for fully automatic spray regulation.

must be taken to apply this evenly. Some materials are not effective on organic soils (e.g. Fen peats). Contact/residual herbicides kill both germinating and growing weeds. Here again, great care in application is required. The best technique is usually to apply to a fine tilth after moulding up and before crop emergence.

Spray materials and application rates

Many spray materials can easily be dissolved in water to give solutions, or may be mixed with water to form stable emulsions. Such materials, once mixed, are easy to apply, and can be effectively sprayed through fine nozzles by 'low volume' machines at rates as low as 56 l/ha (5 gal/acre). Other materials, such as some of the copper fungicides, are suspensions. These may easily be mixed with water but need continuous agitation during work if a spray of constant strength is to be applied. Such materials must usually be applied by machines employing fairly large nozzles, i.e. 'high volume' sprayers. The British Weed Control Council has adopted the following nomenclature in respect of application rates of ground-crop sprayers:

Low-volume	56–224 l/ha	(5–20 gal/acre)
Medium-volume	224–672 l/ha	(20–60 gal/acre)
High-volume	672–1123 l/ha	(60–100 gal/acre)

Some herbicides are more selective in action if applied with a large volume of water. These are usually contact herbicides, whose effectiveness depends on maximum coverage of the weeds. With 'growth regulating' weed-killers, on the other hand, the toxic spray material is absorbed and translocated if only a part of the leaf surface is wetted. A thorough cover is needed for insecticides which act through the stomach or by contact with the insect's cuticle, and also for fungicides of all kinds. A partial wetting may be adequate for systemic insecticides.

With 'low-volume' spraying, the small quantity of spray applied per acre is usually split up into fine droplets, and the spray which strikes the plants adheres to the surface in individual specks. With 'high-volume' spraying the drops are larger, and tend to coalesce and cover the whole surface, any excess running off. High volume spraying is, therefore, more suitable where a complete cover is required. A further advantage of applying high

volumes is that the large droplets, delivered at high pressure, have more penetrating power than the small droplets delivered by low-volume sprayers, and are therefore more effective in achieving a complete cover in dense crops or reaching low-growing weeds in tall crops. Moreover, there is less danger of damage from spray drifting on to neighbouring crops.

The advantages of spraying at low volume when this is practicable are fairly obvious. Machines designed only for low-volume work can be relatively light and cheap, and owing to the small amount of water needed, rates of work are high, and labour costs low.

Some soil-acting pre-emergence herbicides have to be mixed with the upper layers of the soil. Other persistent soil-acting materials may be sprayed on the surface for crops such as maize and beans.

Pre-emergence herbicides for root-crops such as sugar beet may be band-sprayed at drilling, while others may be applied 3–4 days before the crop emerges.

Spraying machinery

The basic essentials of a spraying machine are a tank, a pump, easily cleaned filters in both the suction and delivery lines, a boom and nozzles, a pressure gauge to indicate pressure near the nozzles, a control valve which incorporates an anti-drip device, and an adjustable relief valve which bypasses surplus material back to the tank (Fig. 9.2). No attempt is made here to discuss in detail all of these components, but attention is drawn to a few of the factors involved in choice of equipment.

Tanks

Steel is only satisfactory if properly galvanised or otherwise treated after fabrication to prevent corrosion. Plastic materials of many kinds are increasingly used on account of freedom from corrosion, and ease of moulding into smooth shapes which avoid the difficulty of agitating in recesses and sharp corners.

Where mechanical agitation is provided it is usually carried out by a horizontal shaft with flat blades, rotating at about 100–120 rpm. Paddle tip speeds in excess of 2.5 m/sec (500 ft/min) may cause foaming. Power required for agitation is doubled if speed is increased by a factor of 1.22. Round-bottom tanks are best suited to use of a

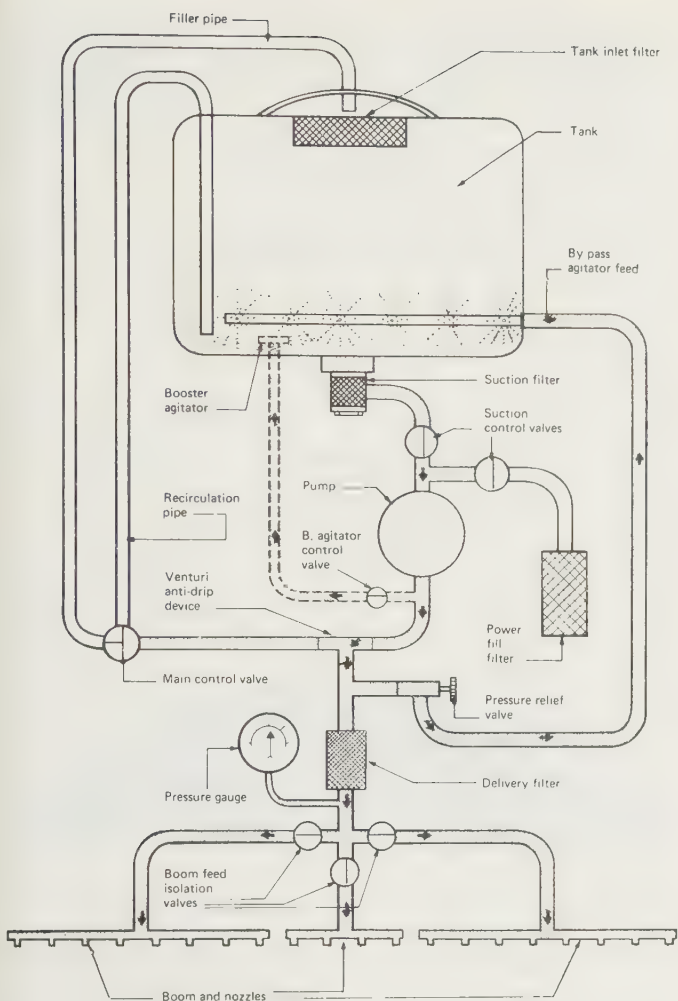


Fig. 9.2 Schematic layout of simple field crop sprayer – spray on.

cylindrical section) is used, and the pipe runs horizontally near the bottom, but offset about 30° from the centre-line, with jets to sweep horizontally across the bottom.

Pumps

Many kinds of pump are employed in spraying machines, and types in general use include diaphragm, medium-pressure centrifugal and low-pressure rotary pumps of various types, notably gear and vane or roller pumps.

High-pressure and medium-pressure piston pumps were formerly widely used for high-performance machines, and are still used by some Continental manufacturers; but they are expensive in first cost, tend to be difficult to maintain in good order and are now less necessary because modern methods of spray distribution do not require the high pressures (e.g. up to 41 bar (600 psi)) which were formerly used in certain types of hydraulic orchard sprayer.

The diaphragm pump principle is attractive because of the complete absence of sliding friction in the pumping mechanism. Compact multi-chamber designs, choice of non-corrosive materials and high-volume production have been combined to make this positive-displacement type popular for multi-purpose machines.

Nylon roller pumps are used mainly for low- and medium-volume sprayers. The nylon rollers are held against the sides of the pump-casing by centrifugal force, and as with gear pumps, the efficiency depends on maintenance of close clearances between the rotating parts and the stationary pump housing (Fig. 9.3).

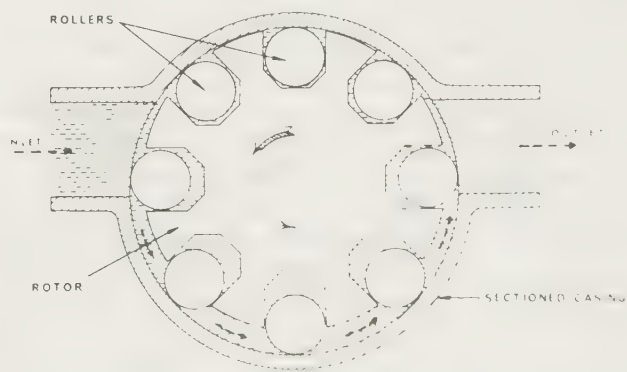


Fig. 9.3 Section of roller vane pump. The rotor is mounted eccentrically in the casing. The rollers are flung outwards by centrifugal force.

horizontal mechanical agitator. Hydraulic agitation is now generally preferred. A pump of fairly high capacity (e.g. 90–135 l/min (20–30 gal/min)) is chosen, and before starting to spray after refilling the tank, the full pump output is first used to circulate the contents. During low-volume work only a small proportion of the pump output is normally needed for distribution, and the rest is recirculated in order to keep the spray well mixed. Work rate on high-volume work may be limited by the requirements of hydraulic agitation. Good hydraulic mixing is achieved if a tank with a curved bottom (e.g. an oval or

When rotary pumps of either gear or roller type are used for pumping gritty suspensions, the performance may fall off rapidly. Diaphragm and centrifugal pumps, on the other hand, are better suited to handling abrasive materials, and they are tending to displace other types for use on universal machines such as are needed by contractors or by farmers with a comprehensive spray programme.

Spray nozzles

Atomisation of spray fluids is usually achieved by discharging the liquid through an orifice under pressure, but a second main method of commercial importance achieves atomisation by breaking up the jet of liquid with a blast of air. Nozzles which do not employ air blast may be broadly divided into two main types: swirl nozzles and fan nozzles.

Swirl nozzles, usually made of brass, stainless steel or plastic consist of a swirl plate, a swirl chamber, a nozzle disc and a cap. A filter is also often incorporated in the nozzles. The spray fluid is given a whirling motion as it approaches the orifice, and the result is a cone-shaped spray pattern. The nature of the spray may be controlled by varying the number and size of holes in the swirl plate, the depth of the swirl plate, the depth of the swirl chamber (thickness of washer) and by fitting discs with holes of various sizes.

Pressure also has a considerable effect on nozzle performance. For a given size and design of nozzle and depth of swirl chamber, the higher the pressure, the higher the throughput, the wider the spray angle and the finer the spray droplets. Though as a general rule, swirl nozzles are used on high-volume sprayers and tend to be operated at pressures in the region of 4–7 bar (60–100 psi) or above, there are swirl nozzles designed to work at pressures as low as 0.7–1.4 bar (10–20 psi).

Fan nozzles may be made of metal, ceramics or plastics. They are usually designed for 'low volume' work, but by selecting nozzles with apertures of suitable size, quite high rates of application can be obtained. Individual filters are normally fitted to each nozzle. Pressures employed with fan jets are usually in the region of 2–4 bar (30–60 psi). Higher pressures may cause too high a degree of 'atomisation', with excessive drift. Fig. 9.4 shows how in one widely used design a diaphragm check valve is employed. The pressure disc assembly of the anti-drip device

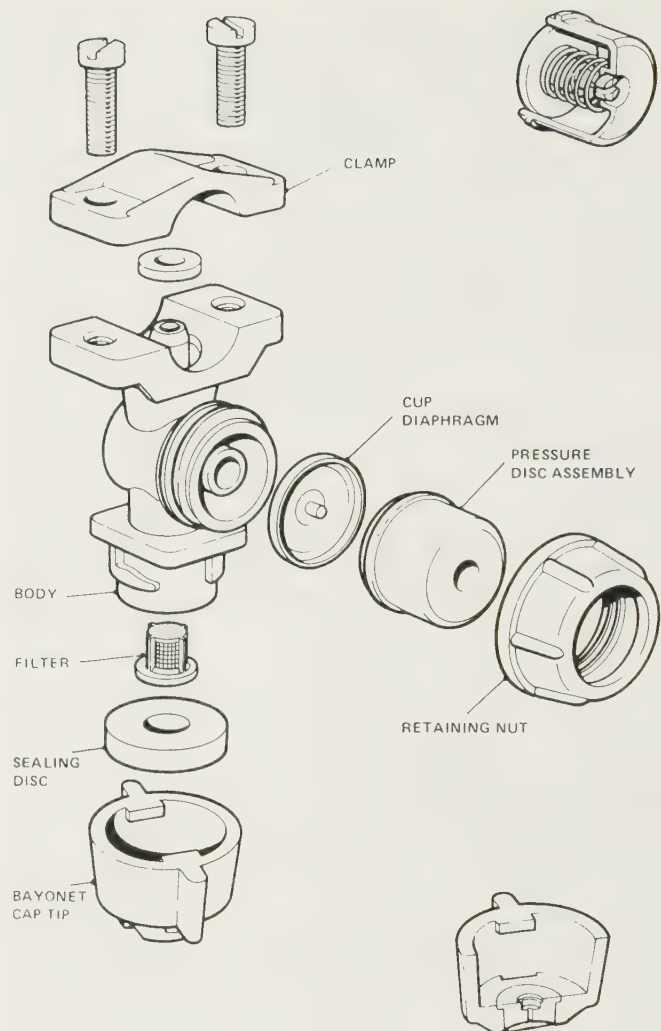


Fig. 9.4 Exploded view of arrangement of self-aligning wide-angle fan jet with anti-drip device consisting of diaphragm and pressure disc assembly. The cap tips are colour-coded to assist choice of the correct size. (Lurmark)

houses a spring-loaded pressure pad, which in operation is moved off seat by the hydraulic pressure of the liquid flow.

Practices in nozzle design and manufacture include injection moulding to very tight tolerances of new materials (e.g. Lurmark Kematal®) chosen for high resistance to spray chemicals, corrosion and impact, as well as wear rates greatly superior to brass and better than nylon or

stainless steel. Designs provide for interchangeability of flat fan jets of 80° or 110° spray angle; hollow-cone jets of disc and core type with spray angle 45° to 90°; and anvil-type flood jets for purposes such as fertiliser application. Assembly of the nozzles and optional diaphragm check valves relies on bayonet fits and snap fits which require no tools for either assembly or dismantling, and ensure that fan jets are fully self-aligning. Colour coding makes selection of the right size simple, and avoids accidental

mixing of sizes. Rapid size changes can be made simply by rotation of clusters of three sizes.

Assessment of the quality of spray spectra is a complex subject which need not to be fully discussed here. A short definition of some of the criteria measurable indicates the scope of the subject.

Volume Median Diameter (VMD) is the number which divides any spray into two equal parts by volume, with one half containing drops smaller than the number, and the other the larger drops. It is measured in microns (μm).

$$1 \text{ micron} = 1 \times 10^{-6} \text{ m} = \frac{1}{25\,000} \text{ in}$$

Number Median Diameter (NMD) is average diameter of drops without reference to volume. The ratio VMD : NMD reflects the uniformity or span of drop production.

Small Drop Volume or Fraction is quantity of spray made up of drops less than a stated size, which may be 100 μm for drops fairly susceptible to drift.

In modern fan-jet ranges, typical 80° tips give a range of VMDs from 200 to 400 μm ; and comparable 110° tips, 200 to 300 μm .

A pragmatic spray classification system adopted by the British Crop Protection Council* divides spray droplet spectra into five categories, *viz* very fine, fine, medium, coarse, and very coarse. For each of these a standard curve shows the normal relationship between droplet diameters and cumulative per-cent volume at a standard rated pressure. Droplet sizes are not easy to measure, so users should follow manufacturer's guidance on nozzle choices.

Accumulated experience indicates that there is no worthwhile advantage, from a drift control viewpoint, in a VMD higher than about 280; and this typically requires acceptance of about 15% of the spray being in drops of less than 100 micron for hydraulic nozzles of medium category and about 20% for fine category nozzles.

Rotary atomisers

A proven method of producing droplet sizes mainly appropriate to the specific spray target is by use of a spinning

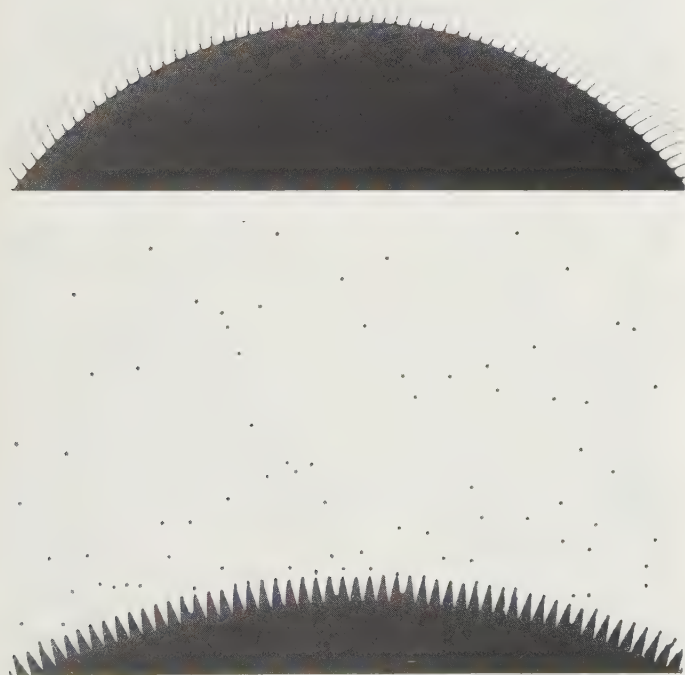


Fig. 9.5 NIAE (Silsoe Research Institute) photographs of droplets produced by rotary atomisers within narrow size ranges.

Top: Ligament atomisation by an experimental disc.

Bottom: Direct droplet formation by a commercial serrated disc. (MICRON Sprayers 'Herbi')

Farm Machinery

disc or discs. The term Controlled Droplet Application (CDA) has been widely applied to the system of droplet size selection chosen by Micron Sprayers whose range of atomisers is illustrated by target list as follows:

Target	Optimum droplet size (diameter microns) ($\mu\text{m} = 0.001 \text{ mm}$)
Flying insects	10.5
Insects on surfaces	30–100
Plant diseases	30–150
Weeds	100–300

In matching sprayer to target need, optimum droplet size should first be chosen from this list, and where necessary a variable-speed motor may be chosen and motor speed adjusted by change of operating voltage, and rate of liquid supply regulated to maintain required density of spray coverage.

Hand-held ULV sprayers

Ultra-low-volume (ULV) hand-held machines powered by dry-cell batteries housed in the handle and utilising a single spinning disc have been widely used in many countries for application of insecticides and fungicides. A typical machine (e.g. Micron ULVA 8) has a 1 litre plastic bottle of spray mixture and produces droplets of approximately 70 microns diameter. Instructions for use specify that there must be a breeze (of 5 to 25 km/h) to carry the drift-propelled spray away from the operator and into the crop area to be treated. Rate of flow of spray from container to disc is regulated by change of size of a flow nozzle.

A normal recommendation is addition of 10–12.5% of an anti-evaporant to the spray mix to prevent too rapid evaporation of the very small spray droplets. The 'Herbi', (see Fig. 9.6) with its 2.5 litre bottle, 250 micron droplets and twin lance can do about 0.4 ha/hr including filling on straightforward work where the lance can be swept over the target at a normal walking speed, fairly close to the ground to minimise drift. Spray volume for such work ranges from about 10–30 l/ha (1–3 gal/acre).

Tractor-mounted CDA sprayers

Tractor mounted CDA sprayers are typically multipurpose machines with spinning discs mounted about

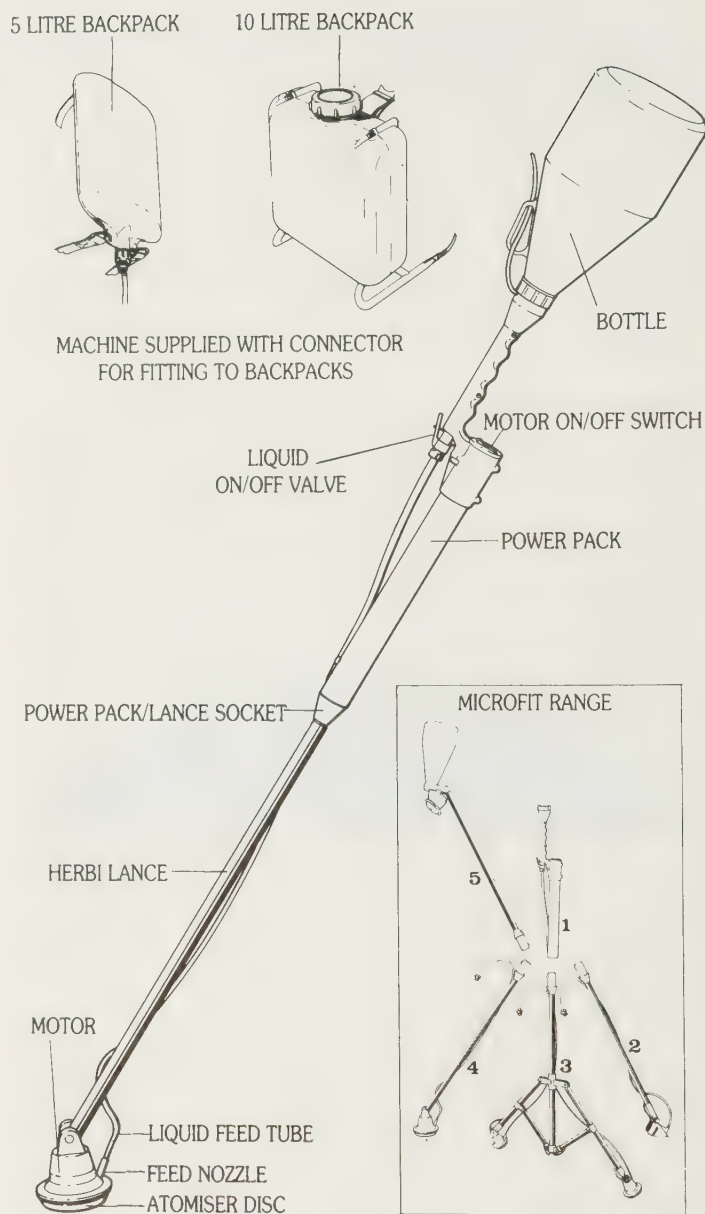


Fig. 9.6 Handheld battery powered Microfit 'Herbi' herbicide sprayer with standard power-pack (1) carrying four torch batteries (R20S D-cells) Herbi lance (4), electric motor which spins the atomiser disc at a constant 2000 rpm and a 2.5 litre bottle attached. The Microfit range includes the optional backpacks, Herbaflex lance (2) for 10 cm to 75 cm swath herbicide use, the Herbi twin lance (3) for swaths 1.8 to 2.4 m, and the Mini-ULVA lance (5) for insecticide and fungicide applications, often well above ground level. (MICRON Sprayers)

1.2 m apart, with electric low-voltage drive and a three-step belt pulley drive from motor to disc spindle giving easy changes of disc speed that result in a range of average drop sizes from about 70 to 300 micron diameter. One of the main attractions of the system to users is that the generally low application rates (e.g. 10–60 l/ha) minimise spray handling problems and lead to high work rates when conditions are favourable. Choice of approximate speed and droplet size range is as follows:

	Speed range (rpm)	Droplet size (micron)	Main uses
Low	2000	250–300	Herbicides
Mid	3500	130–160	Herbicides, fungicides
High	5000	70–100	Insecticides, fungicides

A lighter type of electric drive (e.g. Micromax VS) is aimed at easy conversion of booms with conventional nozzles to 'controlled droplet' atomisers. It features a 3-voltage motor housed within the atomiser cone, and a control switch providing 7, 9 or 12 volts. Motor speed range is broadly set by changing the operating voltage, and there is a self-regulating capacity which maintains a constant density of spray coverage on the target.

Infinite speed variation with ease and accuracy of control is provided by some forms of hydraulic drive, notably one with the hydraulic motors piped in series (e.g. Microcide; Lely Hydraspin).

Spray supply: Objectives include simplicity and accuracy of control; colour-coded interchangeable flow regulator nozzles provide for broad rate bands, while adjustable automatic pressure control can provide fine adjustment. Designs where part of the spray is returned from individual discs to the supply inevitably increase complexity and can add to operational problems.

Combined CDA-air-assisted orchard sprayers

The Micron X-1 atomiser is a three-bladed propeller-driven single-disc cone-fed CDA atomiser designed for ULV applications by air-assisted orchard sprayers. As a retro-fit the atomisers have been widely installed with longitudinal axis in line with the air flow from the original air-blast fan. The atomisers replace the original hydraulic nozzles: each is driven by its integral three-blade propeller,

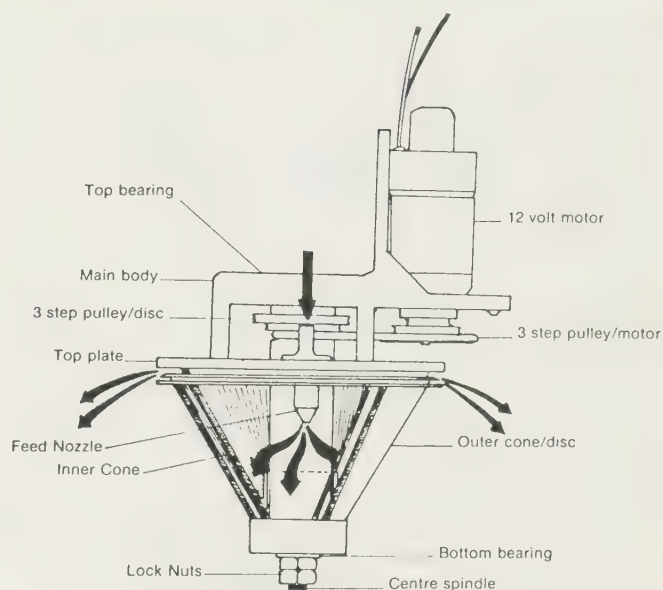


Fig. 9.7 Diagram illustrating principle of operation of multi-purpose atomiser. (CDA Micromax III)

Spray liquid metered by offset feed nozzle into fixed inner cone diffuses into space between this and rotating outer cone: this has round its upper edge a ring of teeth which form droplets or ligamentation according to spray feed rate and disc speed. The rotating teeth are protected by a larger-diameter smooth ring just below. The three-step pulleys give choice of speed and droplet size. Recommended mounting on boom is with axis 15° forward at top.

normally at a speed of 12000 rpm. On the basis of specialist installation by FAST (Faversham) 80 converted machines are annually meeting the spray needs of about 4500 acres of top fruit in Kent. An average saving of chemical of approximately 50% overall has been estimated by users (Fig. 9.8).

Spray boom control for ground crop sprayers

On large sprayers boom length is often 24 m and then there are usually five sections to allow compact folding by hydraulic power. Light castor wheels or, more usually, hoop skids may be used at boom ends to help in avoiding damage to nozzles by ground contact. Positive hydraulic control of both height and angle of the boom are increasingly used.

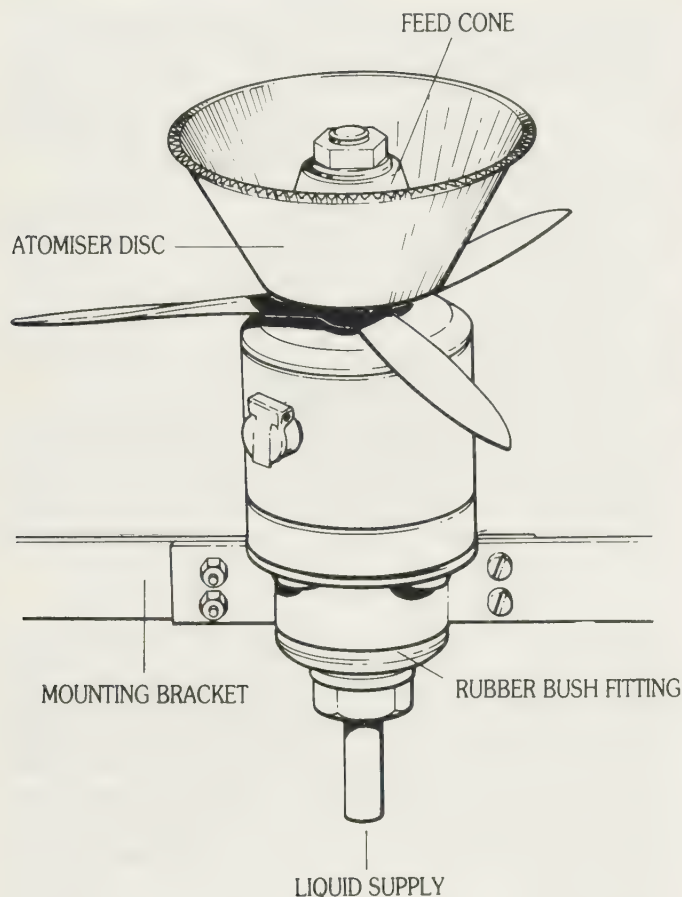


Fig. 9.8 Micron X-1 rotary atomiser for air-assisted sprayers. The small atomisers are usually driven at high speed by the air-flow provided as original equipment for air-blast orchard sprayers: they replace the original nozzles as a retro-fit package. The atomisers are mounted with longitudinal axis in line with the air-flow. (*MICRON Sprayers*)

Independent studies show that required basic factors in good boom performance are stiffness to avoid the extreme distribution irregularities caused by boom whip and yaw, together with a suspension that absorbs shocks due to ground surface irregularities. Except on flat land there must be provisions to ensure that the boom is substantially parallel to the ground surface rather than horizontal on side slopes.

A float suspension employing double diverging (A) links provides a simple way of reducing vertical shocks; it does not of itself keep the boom parallel to a side slope.



Fig. 9.9 Basic elements of NIAE (now Silsoe Research Institute) pattern boom suspension incorporating a steeply converging pair of V-links, located close to the mast and to the centre of gravity of the boom, which keep the boom substantially parallel to the ground on which the rear tractor wheels stand; and a pair of parallel links, located centrally one above the other and equidistant from the boom centre of gravity, in line with the boom raise/lower cable. These prevent the boom from tilting forwards or backwards. The effect of vertical shocks due to ground irregularity may be minimised by adding shock-absorbers arranged in A form just outside the main V support links. (*Lely 'Autoglide'*)

A system developed by Silsoe Research Institute provides for isolation from both vertical and horizontal shocks: the inclined vertical links arranged in semi-V form are supplemented by shock-absorbers and have the suspension point near the centre of gravity of the boom to provide a gimbal effect. The boom stays substantially parallel to a side slope. Horizontal shocks which produce yawing of the boom can result in very erratic spray application rates at the boom ends; this is minimised in the Silsoe Research Institute suspension by use of ball joints on the ends of the links which hold the boom away from the chassis (e.g. Lely 'Autoglide').

Active boom suspension (ABS): As a result of development work by Silsoe Research Institute active vertical boom stabilisation is now available to facilitate use of wide booms and high forward speeds on side slopes (e.g. Lely Autolite ABS). Ultrasonic transducers are used at each end of the boom: these continuously review height of the



Fig. 9.10(a) Specialist self-propelled forward control hydrostatic drive sprayer/distributor with twin-line 24 m spray boom and pack, easily demountable and replaceable by 24 m pneumatic distributor or cheaper and lighter twin-disc model for smaller machines of range. Machine illustrated is top of range 110 kW (148 hp) air-cooled turbo diesel model with 3600 litre tank suitable for large farm or contractor use. All have full hydrostatic four-wheel-drive and demount facility. (Sands)

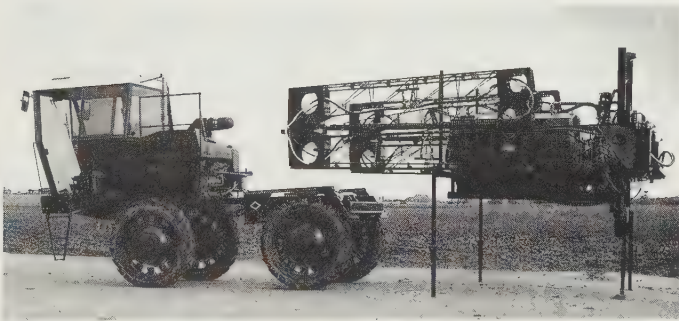


Fig. 9.10(b) Stand supporting spray pack; and power unit on row-crop wheels free for other duties. Demounting of spray pack takes only minutes using three locking clamps and easily fitted jacking legs. (Sands)



Fig. 9.10(c) High-power unit on low ground pressure wheels with 24 m pneumatic fertiliser distributor. (Sands)

sensor above the ground; and a microprocessor integrates the signals and an electrical screw jack is used to maintain boom end heights. The wider the boom the greater are the weight-saving advantages of high-tensile aluminium used in design providing stiffness and durability. Full hydraulic folding is highly desirable for booms wider than 12 m; where ABS is not available a tilt ram with manual control can be a useful option.

Specialist sprayer/spreaders: In broad terms the most successful sprayer/spreaders are self-propelled vehicles developed from the drawing board as dual-purpose sprayer-distributors, with all necessary design attention paid to just the two very similar needs, including use of the vehicle's hydraulic power to assist easy mounting and demounting of first-class equipment for both operations (Figs. 9.10(a), (b) and (c)).

Electrostatic spraying

Advantages of electrostatic charges may include reduction of the numbers of over-sized droplets formed by either nozzles or rotary atomisers: over-sized droplets are likely to be further atomised by the mutual repulsion of the applied electrostatic forces. There is no tendency for mutually repellant droplets to coalesce. An objective is usually to make more effective use of small droplets and so economise on chemical costs. Development based mainly on an earthed spray liquid and induction charging of the droplets has been applied to both conventional hydraulic nozzles with air assistance and to rotary atomisers, using a circular induction electrode mounted on the same shaft as the atomising disc and rotating with it. Voltage used was a reasonable 1500. Interim reports on co-operative orchard trials by Horticultural R.I. East Malling, Silsoe Research Institute and commercial sprayer manufacturers show promising field results. Replicated orchard trials using a Commandair air-assisted sprayer (similar to Fig. 9.18) fitted with 12 electrostatic charge nozzles showed significantly better control of apple mildew in 1988. When the droplets were charged, 30–40% more of the spray used reached and stayed on the target.

A non-replicated trial using a similar Berthoud on apples in 1989, a season of low disease levels, gave an indication of better mildew control where the spray was charged. One of the main attractions of electrostatic charges was demonstrated by a Victair used on Challenger hops for

aphis control in 1989. Charged drops applied at 390 l/ha (35 gal/acre) achieved as good control as an uncharged run using 1100 l/ha (100 gal/acre).

One of the proven advantages of CDA at 40 l/ha compared with conventional medium volume at 225 l/ha is that the reduction in liquid to be handled can easily result in a 50% increase in overall work rate. This can greatly assist achievement of important target dates, and avoidance of spraying in unfavourable weather.

Air-assisted propulsion of spray produced by conventional hydraulic nozzles on modified booms

A method of reducing spray drift in conditions windier than would normally be suitable for spraying is by propulsion of the spray droplets using a curtain of low-pressure air delivered from above the nozzles. The Hardi Twin air-curtain boom sprayer employs 110° flat fan nozzles at 50 cm centres. In a design including patented features a centrally located hydraulic-drive axial-flow fan delivers air into a two-way-tapered flexible duct, located above the boom, and having a continuous slot in its bottom, situated about 30 cm (12 in) above the spray nozzles. The air outlet and nozzles are linked together so that their relative positions are fixed; but the whole assembly is pivoted on the boom so that the entrained spray can be directed from an angle of 25° forward to 25° rearward by a remote hydraulic control operated from the driver's seat. The quantity of air used can range from none to 1500 m³/h per metre of boom width, with resulting air speeds through the slot of up to 100 km/h (60 mph).

Ability to direct the spray effectively into dense crops, with considerable movement of the foliage, normally permits use of appreciably less water, with consequent increased overall work rates. Other substantial advantages experienced by users include an increase of available spraying time at peak periods, and more effective use of spray chemicals due to crop disturbance during spraying.

Ferrag/Degania employs a cylindrical boom sleeve, made of reinforced PVC located in guides, with perforations above and behind each conventional rearwardly angled hydraulic nozzle. This provides claimed initial sleeve exit air speeds of 50 m/s, i.e. 180 km/h or 103 mph. Such speeds are not easily measured, but reliable reports of field experience indicate that effective needed work can be done in wind speeds up to 20 km/h (12 mph). Lower chemical cost resulting from more ef-

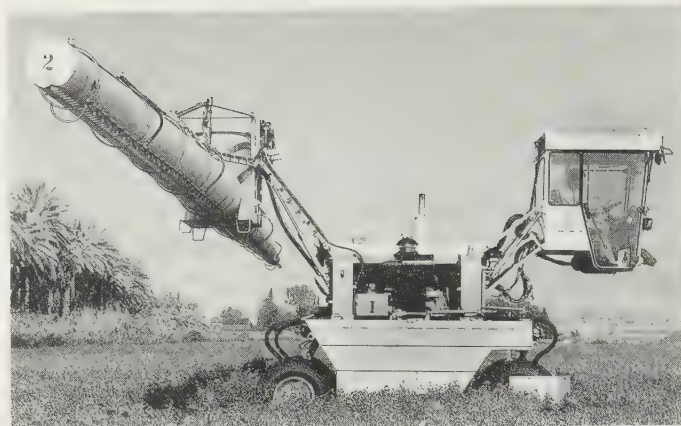


Fig. 9.11 Self-propelled Sleeve-boom Air assisted sprayer (Degan). A low centre of gravity with high ground clearance is assisted by positioning the two spray tanks between the wheels on both sides, and mounting the air-cooled 160 hp engine within the main frame between the wheels. Hydrostatic transmission via individual wheel motors saves weight. The cab uses pressurised air with active carbon filter: hydraulically adjustable cab height gives choice for visibility or suited to work on slopes. The boom folds forward for road travel. The spray line and nozzles during work are located forward of the boom sleeve and slightly below the level of the corresponding air exit apertures located in line behind. The nozzles deliver the spray rearwards at an adjustable angle of about 30° from vertical, so that the droplets are entrained in the air flow at a distance below the air sleeve about equal to inflated air sleeve diameter. (Ferrag/Degania)

fective use of sprays is claimed by users to provide an appreciable saving to offset the capital cost of air-assisted-propulsion machines.

Twin fluid 'AIRTEC' atomisation system

A basically simple air injection technique developed by Cleanacres Machinery is designed for use on good existing sprayers at present equipped with liquid fanjet nozzles of conventional type, or as new equipment. Benefits claimed and confirmed by independent users and official tests include increased work rates, reduced drift, better penetration of dense crops, minimal nozzle wear, and blockages seldom a problem. Most users apply some sprays at reduced spray volumes compared with previous conventional nozzles practice. The air injection technique, developed over several years, has been studied by Silsoe Research Institute and by the International Centre for

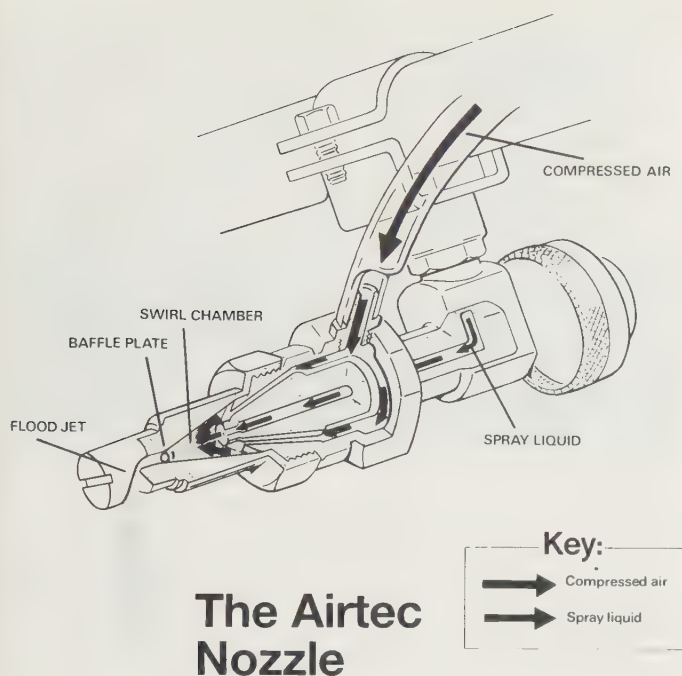


Fig. 9.12(a) Sectioned AIRTEC Nozzle illustrating flow path of compressed air and spray liquid resulting in range of droplet sizes with the larger containing air bubbles which assist spread of the spray on the target and appreciably reduce loss from solid droplets bouncing off vegetation. (*Cleanacres*)

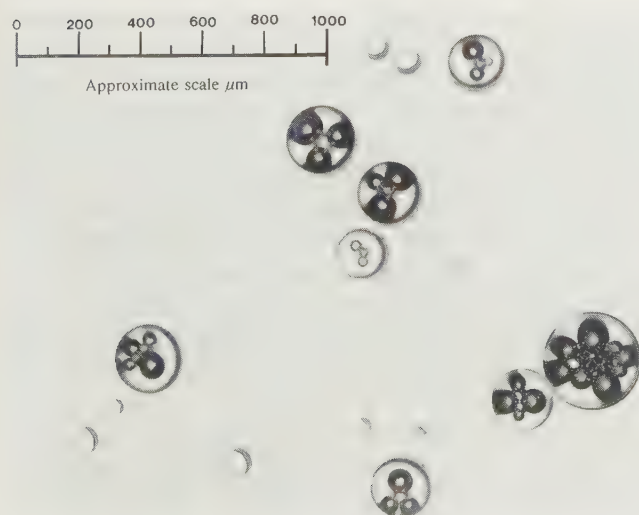


Fig. 9.12(b) Photograph of droplets produced by AIRTEC Nozzle. (Courtesy of Silsoe Research Institute)

Application of Pesticides, and is backed by an RASE Silver Medal award.

Unique features of the nozzle (Fig. 9.12(a)) are a swirl chamber where a curtain of compressed air meets a central flow of spray liquid, and forces it through a baffle plate where it breaks into droplets. The air then sweeps the droplets against the face of a 100° fan flood jet where further atomisation occurs, and the droplets are swept on to the target at a moderate speed by low-pressure air. The work of the Silsoe Research Institute has shown that the droplets vary appreciably in size, and that the larger ones have small air bubbles inside them. The air curtain tends to confine the small drops and restrict their drifting; and when large drops strike the target the air bubbles inside tend to spread the drops easily and reduce bouncing off the crop.

The system is flexible in application rates and in drop sizes by adjustment of liquid flow and air pressure. Practical liquid applications for combinable crops tend to the range 70–100 l/ha (6.2–8.9 gal/acre) with 150 l/ha possible but rarely needed.

Field-crop sprayers

The range of field-crop sprayers is extensive, and the facilities offered with each machine from any chosen group widely variable. The following short list based on tank capacities partially illustrates the wide range of common types.

Tractor-mounted	Trailed
Up to 455 litres	1000 to 1999 litres
456 to 999 litres	2000 to 2999 litres
1000 plus litres	3000 plus litres

In addition there are *specialist machines*, usually tractor-mounted, for such purposes as band-spraying, fertiliser injection and incorporation of chemicals in the soil.

The smaller tractor-mounted machines are designed only for low-volume applications of solutions, but many of intermediate size are capable of a wide range of duties by adjustment of pump pressure and change of nozzle sizes. The more expensive larger machines have facilities such as twin spray lines, either or both of which may be used, to meet a very wide range of duties with a minimum of adjustment.

Developments in cereal growing systems, calling for spraying against both pests and diseases at an advanced stage of growth, have introduced a need for greater clearance beneath axles, a maximum boom height of up to about 2 m, and ability to follow tramlines accurately on turns. With long trailed sprayers provision of an articulated chassis with a vertical pivot halfway between the tractor hitch point and the sprayer axle can help appreciably in ensuring that the sprayer wheels accurately follow those of the tractor.

Self-propelled sprayers

Self-propelled vehicles in general are considered in Chapter 2. The increased importance of spraying and distributing has led to a wide range of types and sizes, many of which are designed primarily to cater for low-ground-pressure or high-clearance work or both. Some are based on high-clearance models of general-purpose tractors; some on high-speed sprung vehicles of truck/tractor type; and many have a purpose-built chassis primarily designed for these limited purposes.

A very wide range of vehicles is already offered by individual manufacturers, and since only a few can be illustrated or mentioned here, this discussion is concerned mainly with principal needs and general trends.

Common needs of larger-scale users include both up-grading quality of work done and work rates, thereby enabling more of the necessary work to be completed in good weather, when optimum effects on crop yields can be expected. Another economic aim must be to reduce the load on multi-purpose tractor time, especially if there is potential scope for reducing by at least one the number of up-to-date multi-purpose tractors needed.

On quality of work, priorities of the specialised vehicle include a suspension system which relieves the boom of severe bumps when working on rough surfaces. Low ground-pressure (LGP) wheels, well matched to the loaded weight, and effective in minimising soil compaction are needed when working on soft, moist land. Lightness of the vehicle itself is important, and users seeking a low-cost option may need to consider also a four-wheel-drive motor-cycle-based ATV with sprayer and spreader mounted on a LGP trailer.

Choice of the specialist vehicle is one of the most difficult that many users ever have to make. It happens



Fig. 9.13 High-clearance self-propelled sprayer/spreader with articulated 'tracker' chassis and mechanical four-wheel-drive equipped with 85.5 kW (120 hp) engine, 2500 litre spray tank and 'Alulight' boom. The multi-purpose chassis is designed for easy removal of the sprayer unit and replacement by fertiliser spreader or pneumatic drill unit. Engine size range is up to 134 kW (*Turbo*). Tyres shown give 940 mm axle clearance; LGP tyres for soft wet soil conditions available. 5 × 2 Synchromesh gearbox gives ten forward and two reverse speeds. Independently variable-speed pto drives sprayer pump or distributor. Spray automatic control by RDS Rate Master. Cab provides air suspension seat, tinted glass and full air conditioning with carbon filtration. (*Willmot Hi-Tracker 2514*)

that for vehicle sizes needing an engine with total power output about 75 kW (100 hp) and above it has been proved that a four-wheel hydrostatic drive system using low speed wheel motors can efficiently meet all of the requirements for working speeds, fail-safe braking and fast road travel, manoeuvrability and lightness, with effective use of LGP tyres for work on wet soils and row-crop tyres for tramlines in tall crops. At the same time there is a wide choice of less powerful vehicles which are able to provide competition on the basis of a light chassis and bought-in mechanical four-wheel-drive transmissions made in large volume primarily for the cross-country truck trade.

For all vehicles some adjustment of wheel track width helps to cover varied user demands, and ability to operate a 24 m boom at normal application rate with one or both sides half-folded is very useful.

One manufacturer with a range of three vehicles has an unusual standard arrangement of the main components

with the spray boom (18–24 m) at the front: cab to rear of front axle: spray tank above and forward of rear axle; and engine at rear (Hardi). The two smaller vehicles employ mechanical rear-wheel-drive only, and the large hydrostatic uses four-wheel-drive and steering.

Band sprayers

Band sprayers are used for spraying row crops in order to save expensive chemicals. They are often used in conjunction with spacing drills, the band spray nozzle being attached to the drill and set to spray a band about 180 mm (7 in) wide just behind the roller. The unsprayed bands between the rows can be kept free from weeds by hoeing. For rear-mounted drill units the spray tank is usually mounted on the drill tool-bar. For spraying of crops that have already been drilled, wide light wheeled nozzle carriers can be attached to a frame mounted on the front of a tractor and supplied from a conventional rear-mounted sprayer.

Calibration

Modern field sprayers are almost invariably pto-driven, and with a given set of nozzles and a fixed pressure, the output of spray per minute remains constant, and the quantity of spray applied per acre is inversely proportional to the forward speed. Most manufacturers supply a chart showing the application rates with various nozzles at different pressures at a standard speed of 4 mph (6.4 km/h), and advise operators to vary the forward speed slightly in order to make minor adjustments of application rate. In practice, natural factors such as slopes make it difficult to keep either engine speed or forward speed constant, and there is therefore a demand for metering systems that give accurate information concerning pressure and forward speed, and also for automatic regulation systems that can make necessary adjustments to either flow rate or forward speed.

Spray regulation systems

Regulating orifice: with this system a pto-driven positive-displacement pump, usually of diaphragm type, delivers to a manifold in which out-flow to the boom and recircu-



(a)



(b)

Fig. 9.14(a) *Spraymeter 2*. Instrument providing easy to use six-channel digital display of speed and area covered, together with volume of spray applied for part and total area in imperial or metric units. (b) *Ratemaster*. Provides flow-based control system, automatic if required. Required application rate is set into instrument by pressing + or – switch to display target figure. (RDS)

lation are independently set by fitting discs with orifices of different sizes. Once the machine has been calibrated by fitting suitable discs, output to the boom depends, within reasonable limits, only on pto speed; and since this, *in any one gear*, is directly proportional to forward speed, dosage is not altered by normal variations in tractor engine speed.

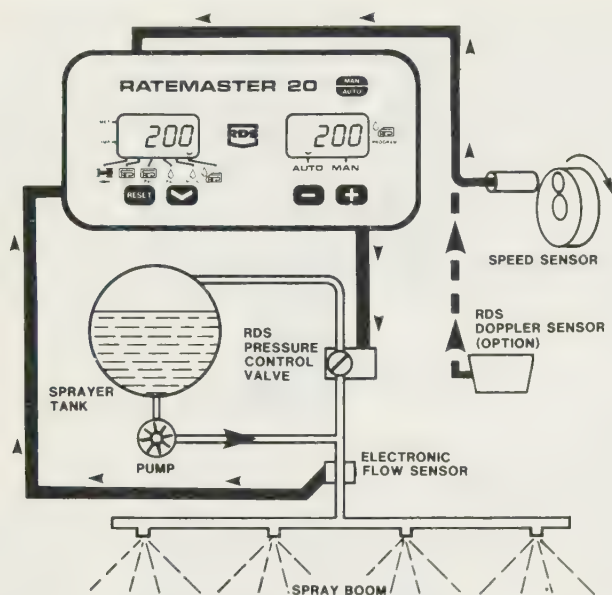


Fig. 9.15 Ratemaster 20 flow-based automatic sprayer control system.

This composite instrument incorporates the Spraymeter 2 facilities and the Ratemaster control (Fig. 9.14). An Area Compensator Interface automatically corrects the measurement of area covered and spray quantity used to allow for use of less than the full boom width in any part of the work done. The required application rate is entered into the right-hand display by pressing the + or - switch. The left-hand display provides forward speed, total area, trip area, trip and total litres used and spot application rate. The required information channel is selected by use of the chevron button. (RDS)

Electronic sensing and automatic controls

Electronic sensing devices are increasingly used to indicate to drivers in 'Q' cabs with tractor-operated sprayers and to operators of self-propelled sprayers whether the equipment is functioning correctly. The essential sensing devices for a sprayer are a flow-meter and a speedometer, both of which must be reasonably accurate. Early electronic instruments were mostly used to indicate to the sprayer operator the extent to which the performance in terms of forward speed and spray output differed from the target fed in to the performance monitor. The aim was to enable the operator to make adjustments to pres-

sure, forward speed or both to bring performance within an acceptable limit. Experience quickly showed that with suitably designed sprayers a microprocessor could go very much farther. In a typical arrangement the forward speed and operating pressure are transmitted to the control instrument which continuously works out pressure changes needed to compensate for speed variations and makes the necessary changes via an electrically operated pressure control valve. The results were so successful that in a very short time automatic control was clearly the way of the future, and this microprocessor advance is completely in line with similar developments in machines such as combine harvesters. The two types of speedometer used are identical with those used on tractors for general tractor duties such as limitation of wheel slip, and both are briefly described in Chapter 2. The wheel magnet type is cheaper but more sensitive to ground conditions. The radar sensor (e.g. Dickey-john; RDS) gives a true measure of speed regardless of soil conditions. This is mounted beneath the vehicle to point downwards at an angle of 35°. It emits a low-intensity microwave energy beam, the frequency of which varies according to speed. The control unit continuously compares ground speed with pressure, and regulates the control valve for a constant application rate. Use of a large servo-control flow valve permits rapid reaction to changes in ground speed.

In another radar control system (e.g. Air PAM (Sands)), the speed sensor signal is converted to an air pressure signal proportional to forward speed. A butterfly valve located in the return-to-tank spray line produces maximum spray pressure when fully closed. This valve is automatically opened or closed as forward speed varies from the set target, normally 9 km/h for this machine in good conditions. Where a compressor is provided to operate spray controls, pneumatic power may also be used for some operations such as boom folding. More usually, controls of spray pressure and flow in tractor-operated sprayers are by solenoid-operated motorised valves. The control box housed in the tractor cab may be a fairly complex instrument, as where each section of a five-section boom needs independent flow control in addition to on-off and pressure regulation. Control boxes have rapidly become a key feature in sprayer selection. Powered raising, lowering, tilting, folding and opening of booms requires a considerable amount of power for sufficiently speedy execution, and this is normally provided by the power unit's built-in hydraulic system.

Developments in automatic chemical injection: A disadvantage of some current conventional pressure operated automatic regulation systems is that pressure changes in the spray liquid, in addition to changing nozzle outputs, also alter the drop size spectrum of the mixed spray. Large pressure changes are sometimes needed to correct for relatively small changes in forward speed, with the result that an excessive formation of very small drops may sometimes accompany higher forward speeds.

A radical method of improving automatic dosage regulation involves keeping the active chemical and the water in their separate tanks on the machine until they enter a mixing chamber immediately before passing to the spray boom. The water flow is maintained at a constant level: only the input of chemical is directly regulated in proportion to forward speed changes.

Potential advantages of the system include use of a reasonably cheap spray metering pump which actually works on water at low pressure in an injection loop (Fig. 9.16) to displace upwards the piston in the chemical transfer cylinder.

To refill the transfer system with chemical the outlet from the water pump is set to recirculate the main tank water up through a venturi which draws the water down out of the metering cylinder, together with the piston and refill of chemical. Systems involving metering pumps are now commercially available, but are relatively costly. A system developed by Silsoe Research Institute (Fig. 9.16) has the potential advantages of complete enclosure of the chemical and the certain major advantage of a system which keeps the water and chemical separate until application.

A major advantage of the design is the separate storage of water and chemical until application.

Blower or air-carrier sprayers are mobile, automatic machines which employ an air-stream to carry the droplets to the trees, rather than depending on the energy of hydraulic pressure. They can handle smaller liquid droplets (75–100 microns) effectively, whereas droplet size with the hydraulic machines usually ranges from about 200 to 400 microns.

The nozzles may be arranged in a semi-circle, or in a complete ring across the air-stream, or in a line along a kind of fish-tail. Some machines have specialised nozzles which can only be used with air-carrier equipment. One of these, the shear nozzle, is extremely simple in principle. The liquid is fed at low pressure through a small orifice

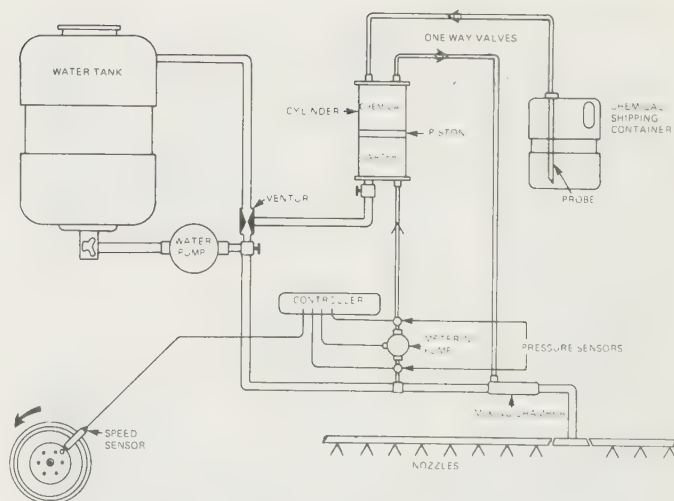


Fig. 9.16 Pesticide injection metering system.

The proposed system is for adding to a conventional sprayer. A main feature is use of a metering pump which always acts on water only, extracted from the main nozzle water supply when the metering pump is actuated by signals from the controller. The water flow to the nozzles is maintained at a constant level by the main spray pump: only the input of chemical is regulated directly in proportion to forward speed via signals involving the pressure sensors. (*Drawing Silsoe Research Institute*)

into a high-speed air-stream. The air shears off the droplets and carries them to the target.

Many of the orchard sprayers now used on holdings where production of top fruit or hops are major enterprises are of the air-carrier types, examples of which are illustrated in Figs 9.17 and 9.18. They are mobile automatic machines which are capable of handling small liquid droplets (75–100 microns) effectively, whereas droplet sizes from types of hydraulic nozzles formerly used for top-fruit spraying usually ranged from about 200 to 400 microns. As already described earlier there can be considerable advantage in using CDA-type rotary atomisers to create a more uniform range of small droplet sizes, and some development of combined new CDA/air-carrier machines using the Micron X-1 atomiser for initial droplet production seems possible.

Maximum advantage from the use of air-carrier sprayers is achieved when small volumes of concentrated or semi-concentrated liquids are applied. For example, application rates as low as 5 gal/acre (56 l/ha) on a fairly well-grown orchard have been applied successfully when using undiluted lime-sulphur. Machines specially designed for such

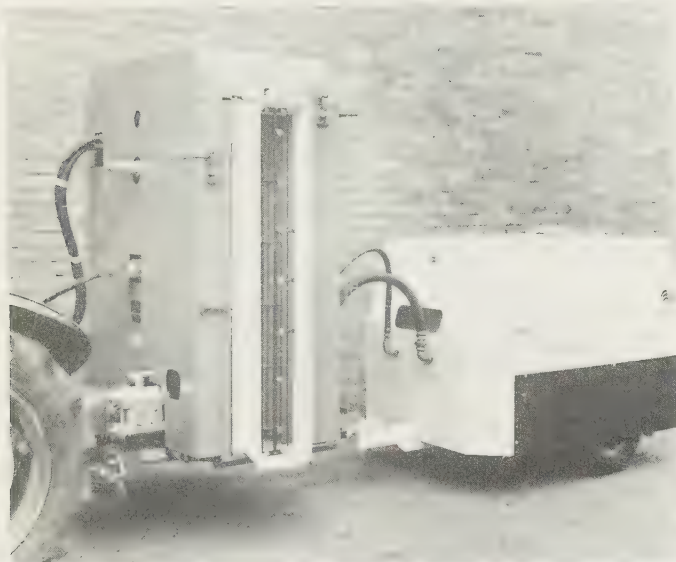


Fig. 9.17 Mounted orchard sprayer with trailed tank and large volume low-velocity air propulsion from hydraulic nozzles on both sides. Designed for work in blackcurrants, raspberries, gooseberries, etc. (*Drake and Fletcher*)



Fig. 9.18 Fully trailed 'mist-blower' sprayer employing 35 000 ft³/min air at 60 mph (96 km/h) and a wide-angle constant-velocity universal joint accurately positioned by the drawbar pivot pin on sprayer, allowing smooth drive on tight turns. The six-cylinder plunger spray pump has output 21 gal/min (190 litre/min) for spraying and the same amount for recirculation at 250 psi (17.25 bar). (*Drake and Fletcher*)

concentrate spraying need only a small tank, and can be relatively inexpensive compared with high-volume sprayers. There is some saving of spray owing to avoidance of 'run-off', and the job is so easily carried out by a single operator that there is little difficulty in spraying very frequently. There are, however, few spray materials which are as suitable for concentrate application as lime-sulphur, so most growers wish to spray at medium or high volume as well as at low. The most widely used air-carrier sprayers can be effectively employed over a range of medium volumes from about 20 to 150 gal/acre (224–1680 l/ha), and spray manufacturers have developed a range of sprays suitable for application at such rates. A difficulty that may sometimes occur at dosages in the region of 50 gal/acre (560 l/ha) is double-dosing without run-off. With some materials, notably lime-sulphur, this can sometimes produce a serious scorching effect.

Air-carrier sprayers which are designed to work at high volume use a large volume of air at a moderate discharge velocity (about 125–140 mph (200–225 km/h)). Centrifugal or axial-flow fans may be employed and the machine can often be set to spray either one or both sides at once, or varying included angles to suit the size of the trees. A typical machine has a tank of 200 gal (910 l) capacity and a maximum output of about 20 gal/min (91 l/min).

Choice of fruit sprayer

Where top fruit is the main consideration and there is a considerable variation in size and spacing of trees, there is much to be said for an air-carrier type with nozzles arranged in a pair of fish tails, which can be used either to spray both sides of the machine, or can be arranged alongside one another to concentrate the whole of the spray on tall or dense trees. A specialist top-fruit grower may wish to supplement such a machine with a very low-volume machine designed essentially for concentrate spraying.

One of the main reasons why an air-carrier sprayer is preferable to a hydraulic sprayer for top fruit is that the hydraulic type needs a very large pump, tank and masts to cope with tall trees. All of these are undesirable, especially tall masts, which require endless adjustment of nozzles and cause intolerable mechanical difficulties.

For strawberries and bush fruit a hydraulic sprayer capable of high-volume applications (150 gal/acre (1680 l/ha)) when necessary can be satisfactory. There

may, however, be a need to fit booms specially designed for particular crops. Thus, for strawberries, it is useful when spraying dense crops to trail a light bar which can roll over the row tops in such a way that the leaves are bent over as the nozzles pass. The nozzles themselves are arranged to spray from both sides of each row, as well as from above.

One of the current needs in orchard work is to be able to spray with weedkillers a swath adjacent to the tree trunks, which cannot easily be kept mown. For this purpose a tractor-mounted under-tree spray boom with hydraulic nozzles may be used. The boom is carried on a castor wheel, and the end, which projects beyond this wheel, is spring-mounted and carries a roller to help it to work round the tree trunks.

Portable mist-blowers and dusting machines

Field-crop trailed or mounted dusting machines were formerly often used in preference to spraying for routine protection against potato blight, because of ease and speed of use due to freedom from water transport and mixing problems. Dusts were, however, generally less effective than sprays, and dusting of field crops on a large scale in Britain has virtually disappeared.

For smaller-scale horticultural work, many dusts have been replaced by oil-based sprays applied without any addition of water by small engine-operated mist-blowers which are carried on the back. A 1 hp machine weighing barely 5 kg can achieve a work rate of about 1 ha/hour in ground crops such as lettuce.

A few chemicals, particularly fungicides for indoor use, are prepared as lightweight dusts. For these, a hand-driven or motorised shoulder-carried blower is needed to secure even application.

Granular insecticide and herbicide application

Several systemic insecticides and a few non-selective herbicides can be applied in granular form. The granules may be sown with tubers in the case of potatoes, broadcast on the soil surface, placed in a band on the soil along the crop rows, or funnelled into the foliage of the growing crop.

The granules used vary considerably in size, but the

most commonly used are a medium size, e.g. from 10 to 40 mesh.

The advantages of using granules are varied. In some cases as with dusting, avoidance of the need to supply water for spraying is a factor. More important are the simplicity of the equipment, the usually long-lasting effect and suitability for use in windy weather when either spraying or dusting is impossible.

The simplest type of application equipment consists merely of a unit like a spacing drill, usually with an agitator, a simple force feed, and adjustable delivery spouts. Each hopper, which has a capacity of about 0.5 ft³ (14 dm³), can deliver to two rows. More complex equipment includes dual-purpose fertiliser distributor/applicators using a pto-driven blower to transport the metered granules to outlets spaced along a wide boom. Some dual-purpose machines use the same nylon rollers, suitably adjusted, for delivering both fertilisers and granules: others have two easily interchanged sets of metering rollers. A typical distribution rate for an overall herbicide (e.g. for wild oats and black-grass) is 22.5 kg/ha (20 lb/acre).

Herbicide 'wipe-on' applicators

Some herbicides (e.g. Glyphosate) can be effectively applied by rope wicks impregnated with a fairly concentrated solution, and set to contact weeds which grow taller than the crop. This treatment particularly suits problems such as weed beet or bolters growing in sugar beet. The simplicity, ease of use and low cost of use of rope-wick applicators has resulted in preference for this wipe-on technique in competition with more complex devices. In one effective type (Fig. 9.19) the chemical is fed to the rope wicks via a stainless steel metering tube in which pressure can be regulated. The wicks are arranged in V-form ahead of a light, folding tubular boom, usually rear-mounted with working width about 6 m (20 ft). The sealed boom members provide the air pressure reservoir. Control of weed beet, which may produce several new crops of weeds at intervals of a few weeks in mid-season, requires repeated applications. The value of the machine is that this can be quickly done, and flow rate of the chemical can be easily varied to suit the level of the infestation. Front mounting can result in transfer of herbicide from treated plants to crop plants by tractor wheels.



Fig. 9.19 Rear-mounted herbicide wick-on applicator with wedge arrangement of wicks and pressure regulated spray supply system. Each V-section is fed via a stainless steel metering tube; flow rate can be varied from cab to suit weed infestation density. (*Vicon 'Wedge-Wik'*)

Fig. 9.20 The helicopter can spray effectively in situations where trees and buildings make operation difficult for fixed-wing aircraft. (*National Association of Agricultural Contractors*)



Below-ground application of chemicals

Specialised machines are available for purposes such as injection into the soil of chemicals for control of potato root eelworm. A Dutch machine consists essentially of a compressor which delivers and atomises liquid beneath a number of broad shares. The surface soil is finely pulverised and is finally pressed down by a hydraulically driven roller to prevent gas escape. Use of such machines in Holland permits potato-growing on a short rotation in spite of eelworm infestation.

For control of some rhizomatous weeds such as couch, herbicides may be applied to the soil during use of a conventional rotary cultivator, the liquid being sprayed into the curtain of soil as it falls after being thrown up by the rotor.

Aircraft use for spraying

Development of use of ground-operated sprayers with booms up to 24 m (80 ft) wide, together with extremely strict regulations regarding aerial spraying, have combined to reduce the number of licensed aerial spraying operators

in Britain to possibly less than a dozen. Most of the remaining machines are helicopters which have the advantage of travelling at only about 35 mph when spraying, and of having the spray nozzles or atomisers only 4–6 ft (1.2–1.8 m) above the crop, into which the spray is forced by action of the rotor blades. The Micron X–15 rotary atomiser with three-speed D.C. Electric drive and 15 discs individually fed via a hollow shaft is designed specifically for use by helicopter, using the aircraft's 12 or 24 volt D.C. power. There are no substantial areas of need in Britain for aerial application of fertilisers such as exist in New Zealand on steep slopes used mainly for sheep grazing. For work on small rough-terrain areas involving spraying, fertiliser distribution or pesticide application, small four-wheel-drive vehicles specially developed for such conditions are increasingly used.

Safe use and disposal of agrochemicals

All work on food production is increasingly subject to legally binding requirements aimed primarily at ensuring the health and safety of people in any way concerned. In the special case of use of poisonous agrochemicals there are many specific regulations concerning safe procedures which apply to employers, employees and sometimes producers working on their own behalf. Subjects which should be considered by all operators but will not be

discussed here include a minimum standard of training for all who use spraying machinery; use of protective clothing; avoidance of causing spray damage to neighbours or bystanders, and of environmental pollution by careless disposal of toxic wastes.

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Pumps and Irrigation Equipment

An ample supply of pure water, properly distributed, is necessary for technical efficiency on stock farms, permitting maximum productivity from controlled intensive grazing of leys, and saving labour about the buildings. A modern dairy farm must have a plentiful water supply. Piped water also greatly facilitates all other kinds of livestock enterprises. Many farms are unable to draw upon a public water supply, and even where available it may be economic to install a pumping plant where there is a suitable source of water.

The pumping outfit installed must be suited to the form of supply. The ideal supply is from a true artesian well or from a natural reservoir at a sufficient height to provide a service without pumping. Such supplies are rarely available, but open springs, lakes, streams and wells of various kinds from which water may be pumped are more common. There is, of course, a danger of pollution in many such sources, but the water may be suitable for stock if not for human consumption. Wells and springs should always be thoroughly tested before embarking on any extensive water supply scheme.

The water requirements of farms vary greatly. In arriving at an estimate of the need, the following consumption figures may be used as a rough guide:

	<i>Per head Gal</i>	<i>per day Litre</i>
Cows in milk – for drink	17	75
Cows in milk – for cleaning, wash down and milk cooling	17	75
Cattle not in milk	10	45
Pigs	3	15
Poultry on range	0.07	0.3
Poultry indoors	0.13	0.6
Domestic (sewered four persons)	112	500

Glasshouses need up to 600 gal per acre (67 000 l/ha) per day, and cold frames about half this quantity.

It is usually necessary to provide a storage reservoir near to where the water is chiefly required. If the topography is suitable, an elevated tank may be used. This should be at least 6–9 m (20–30 ft) above the taps, milk coolers, etc., at the farm.

Where high pressures are needed (e.g. 40 psi (2.75 bar) for a power jet or for irrigation), use of a gravity tank is likely to be impracticable, since it would need to be 27 m (90 ft) or more above the point of use. (A pressure of 1 psi (0.06895 bar) is equivalent to a static head of 0.7 m (2.3 ft). The advantage of employing a large-capacity gravity tank is that it provides an adequate reservoir against peak demands, which may exceed the capacity of the pump.

There are, however, many situations where use of a gravity tank is impracticable. Where electricity is employed for pumping, a good alternative is a pressure tank with an automatic control switch. This has the great advantage that the pressure tank can be situated anywhere convenient near the pump. The pump delivers the water through a non-return valve into the closed pressure tank, which is automatically maintained about three-quarters full of air. When a tap is turned on anywhere in the delivery system, water is drawn from the tank, and after the pressure has fallen to a certain level, the pump is automatically switched on. In this case it is uneconomic to have a very large tank, and the output of the pump must be equal to the peak demand. The whole outfit can work very satisfactorily, with a minimum of maintenance.

The type of pump required depends mainly upon the ‘suction lift’ and the ‘delivery head’. Almost any kind of pump may be used for raising water short distances (up to about 4.5 m (15 ft)); in such cases the simplest and cheapest types of pump may be chosen. But where water

has to be raised from a deep well, one of the many types of pump specially designed for this service must be chosen. Deep wells are those in which either the pump must be placed below ground level in order to be within suction distance of the water, or a special type of deep-well pump must be employed.

Modern pumps for operation by internal-combustion engines or electric motors include the following three main types which are in general use on farms:

Plunger pumps, suitable for deep wells.

Piston pumps, suitable for shallow wells.

Centrifugal pumps.

Other types include propeller, rotary, semi-rotary and diaphragm pumps together with various types of endless conveyor for handling semi-liquid materials. Reference has already been made in Chapter 8 to a range of pumps and conveyors used for handling slurry, while pumps used in spraying machines have been briefly discussed in Chapter 9.

Plunger pumps

A type formerly widely used for deep wells but now often superseded by more compact pumps is the 'plunger' pump, which is placed in the well and is operated through a system of rods by a crank or lever above the ground. Operation of the crank or lever may be by a windmill, an engine or an electric motor. The pump chamber, which may either be immersed in the water or placed on a platform just above, consists of a vertical cylinder. The plunger is fitted with transfer ports and a delivery valve. The chamber is connected to the rising main and a water-tight gland surrounds the pump rod. The rising main is usually screwed to the top of the pump chamber, extending it to the top of the well; the pump rod then works inside this pipe, and as the pipe is of slightly greater diameter than the plunger the latter may be easily withdrawn for occasional inspection or repair.

A modern electrically operated plunger pump has the well-head gear immediately above the rising main. The motor drives a reduction gear by V-belt, and the plunger usually operates at 25 to 90 strokes per minute. The water can be raised about 120–150 m (400–500 ft) above the plunger if necessary. A typical 1 hp (0.75 kW) pump operating with a 70 mm ($2\frac{1}{2}$ in) cylinder at 45

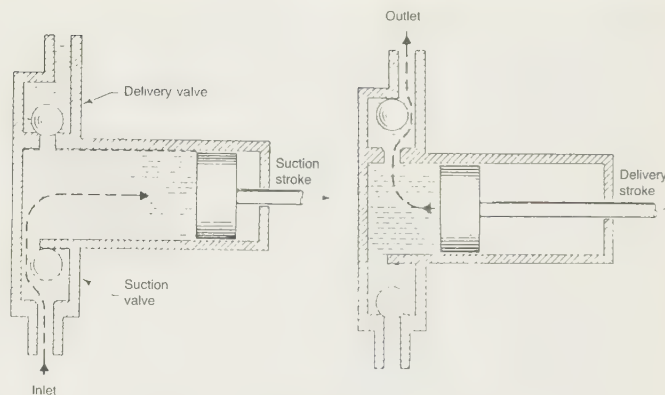


Fig. 10.1 Action of a piston pump.

strokes per minute in a well 41 m (135 ft) deep against a total head of 69 m (225 ft) may be expected to deliver about 1230 l (270 gal) per hour. There is a range of plunger pumps suitable for most farm requirements.

Piston pumps

High-speed electrically operated piston pumps are suitable for use in conjunction with shallow wells. They consist of a close-fitting piston reciprocating in a small cylinder which contains both inlet and outlet valves. The volume of the cylinder is small, displacement per stroke usually being only about 0.04 ($\frac{1}{15}$ pint), and the pump is almost invariably horizontal and double-acting. A typical installation with a 0.25 kW ($\frac{1}{3}$ hp) motor will deliver 1350 l (300 gal) per hour against a total head of 36 m (120 ft).

Low-speed high-duty piston pumps will deliver against very high heads. These need a reduction gear and are therefore more expensive than the high-speed types.

Centrifugal pumps

Centrifugal pumps operate on the same principle as a propeller or fan. Simple types are not as efficient for small duties as piston or plunger pumps, but have the advantage of less complication and maintenance. In the simplest type, an impeller, consisting of curved vanes, is driven at high speed inside a disc-shaped casing. Water enters at the centre of the casing, and the motion of the impeller pushes it up the delivery pipe, which is attached

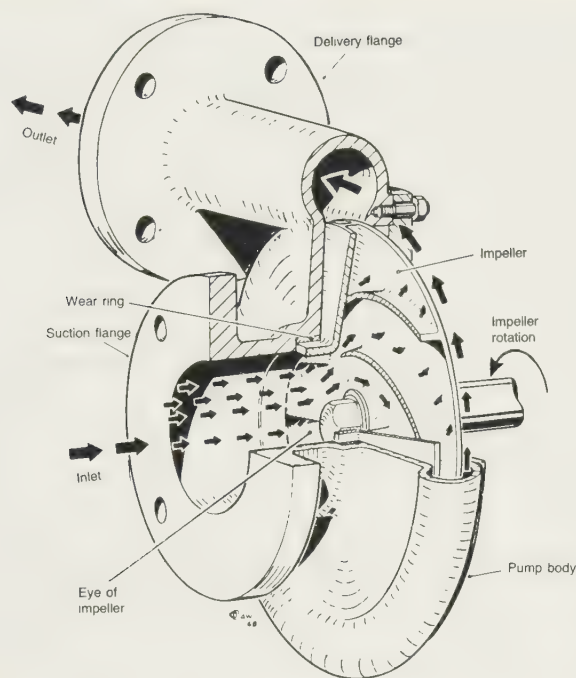


Fig. 10.2 Action of a simple centrifugal pump. (Gilbert Gilkes and Gordon)

tangentially to the outer rim of the casing (Fig. 10.2). Such simple pumps are not self-priming.

Modern centrifugal pumps are usually of a modified design, in which there are inclined vanes on the inside of the pump chamber, and the rotor consists of straight radial vanes. With this type, inlet is at the top of the pump beside the outlet, so the pump is never empty and is self-priming (Fig. 10.3).

The pump housing consists essentially of a sandwich of three components: a plain distance ring, which is a fine clearance fit round the impeller when assembled, and a pair of disc-shaped castings, each of which has C-shaped channels cast on the side adjacent to the impeller. The method of operation depends essentially on the tendency of the vanes to drag water around with them, and the shape of the channels in the stationary housing. In each housing there is an area where the channel fades out, and in this blank area there is only a fine clearance between the impeller and the housing. As each of the vanes comes abreast of this plain area, the water which is being dragged round with the vanes can go no farther, and can only

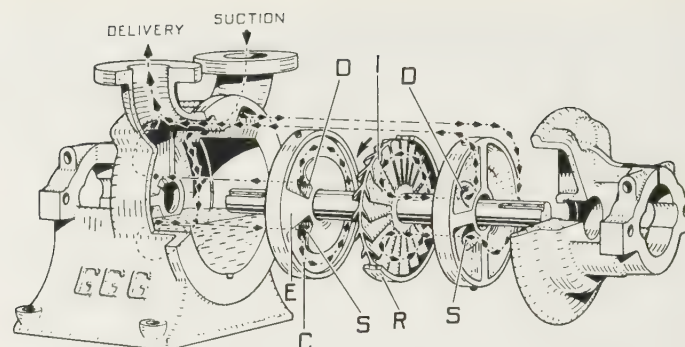


Fig. 10.3 Action of a regenerative self-priming centrifugal pump. (Gilbert Gilkes and Gordon)
I Impeller, C Channels in housing, E Flat area, D Discharge ports, S Suction ports, R Distance ring.

escape through the discharge ports which are at this end of the C. Similarly, having passed this area, the vanes next come to the beginning of the channel and here the suction created by the vanes carrying water away from the closed end causes water to be sucked in through the inlet port and the pump inlet.

Multi-stage pumps have two or more rotors mounted on the same shaft in separate casings, water from the first in the series being delivered to the inlet of the next. By this means the working pressure is increased at each stage, and centrifugal pumps which will work against heads of up to 305 m (1000 ft) can be constructed.

Submersible electric pumps

A very neat and efficient type of pump that may be employed for deep wells where electricity is available is the submersible multi-stage centrifugal type. The unit consists of a motor and pump which are lowered into the water, attached to the rising main. The pump is mounted immediately above the motor. The motor itself is of squirrel cage induction type, with a thin alloy cylinder to protect the stator from the water. The rotor is of non-corrodible metal, and is immersed in the water.

Current is conveyed to the motor by rubber-sheathed cable. Control may be by a push-button starter, a float switch working on an open reservoir or by an automatic pressure system.

A great advantage of the submersible type of pump is the ease of installation. The outside diameter of the unit

is generally less than 150 mm (6 in), and it is easily lowered into the well at the end of the rising main, and withdrawn when necessary for servicing.

Portable centrifugal pumps

A handy type of pump for general farm use is the portable self-priming centrifugal type. The best examples of this type are fully automatic in their self-priming action; and with a small internal-combustion engine attached they are easily portable by one man.

The capabilities of such pumps are indicated by the example of a tiny engine-driven outfit, weighing less than 25 kg ($\frac{1}{2}$ cwt) when built of aluminium, which is capable of pumping 13 500 l (3000 gal) per hour with a suction lift of 4.5 m (15 ft) and against a total head of 9 m (30 ft). Such pumps are able to deal satisfactorily with water containing up to 25% of solid matter.

Propeller pumps

A propeller pump is a low-lift type which is suitable for tractor operation on work such as flood irrigation, or filling a reservoir from an adjacent river. A typical model has the impeller, which is driven at 1350 to 1750 rpm, housed in a 250 mm (10 in) diameter tube, the foot of which is immersed in the water supply. When the pump is driven by a 540 rpm pto it is usually necessary to arrange a speed increase of about $2\frac{1}{2}:1$.

Deep well jet pumps

These are suitable for use in wells up to about 107 m (350 ft) deep. The principle of operation is similar to that of the injector. A pump of normal type but capable of working at fairly high pressure, standing on the surface, delivers water through a pipe at the bottom of the well. There it passes upwards through a venturi, at a point where well water can be drawn in. The ambient waters are then forced up the rising main pipe.

Rotary pumps

In their simplest form, these consist of a pair of spur gear wheels, which mesh together in a suitable housing and carry the liquid round in the spaces between the gear teeth and the outer casing. Such pumps are not generally

used for water supply or for pumping gritty fluids, but are commonly used on internal-combustion engines for pumping oil from the sump to the principal bearings, on tractors for the hydraulic system and sometimes on spraying machines. Other rotary pumps work on a similar principle, but have the rotating parts of various shapes.

Roller vane pumps are widely used on simple spraying machines. These pumps are typically mounted directly on the pto and driven at a speed of 400–600 rpm. The rotor is mounted eccentrically in the housing, and the rollers are thrown out against the casing by centrifugal force (see Fig. 9.3). Working pressure is usually moderate, but pressures of 250 psi (17.2 bar) or more are possible with a pump in good condition.

One type of rotary pump (Fig. 8.33) used for many purposes, including slurry pumping and spraying, has a single rotor which revolves inside a fixed stator made of rubber. The stator has the form of a double internal

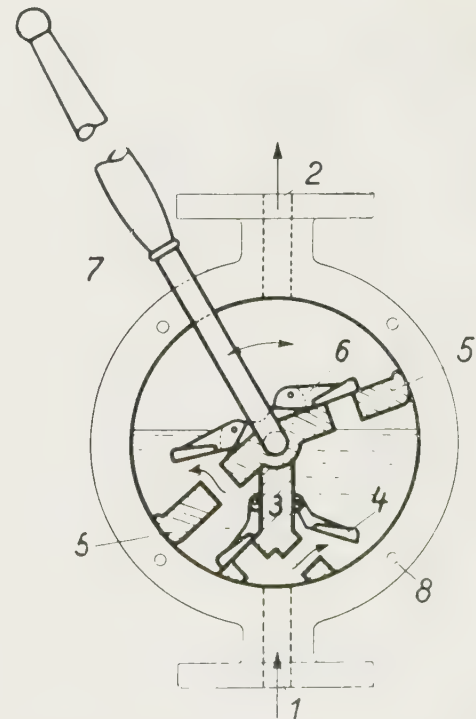


Fig. 10.4 Semi-rotary pump.

1 Inlet, 2 Outlet, 3 Stationary partition with 4 Valves, 5 Semi-rotating partition with 6 Valves, 7 Handle, 8 Casing.

helix. The rotor is also helical, but of half the pitch. The rotor maintains a seal with the stator, and this seal travels continuously along the stator as the pump operates.

Semi-rotary pumps

This is a compact, efficient, double-acting type that is popular for the hand pumping of water, oil, etc. Its lightness and portability make it useful for work where a power-driven pump cannot be used (Fig. 10.4).

Diaphragm pumps

These were formerly only suitable for short suction lifts. A simple hand-operated type has a rubber or chrome leather diaphragm in place of the piston of the lift pump. The diaphragm has a valve in its centre, and as it is

moved up and down by operation of the handle, the delivery valve opens and closes alternately with a foot valve. The diaphragms are easily and cheaply renewed, and the complete absence of sliding friction permits a fairly high efficiency and a capacity for dealing satisfactorily with muddy water. Modern power-driven diaphragm pumps used on spraying machines normally use a synthetic rubber diaphragm. Normal operating pressure is about 100 psi (6.9 bar) and the pumps are designed for double-acting operation at a pto speed of 540 rpm (Fig. 10.5).

Capacities and efficiencies of pumps

The theoretical capacities of reciprocating pumps may be calculated by multiplying the product of the length of stroke, the area of the cylinder and the number of strokes per unit of time. In Imperial units,

$$\begin{aligned} \text{theoretical hp} &= \frac{\text{ft lb work per min}}{33\,000} \\ &= \frac{p \times a \times s_{ft} \times n_{min}}{33\,000} \end{aligned}$$

where p = pressure (psi)
 a = piston area (in²)
 s_{ft} = length of stroke (ft)
 n_{min} = number of strokes per minute

In SI units,

$$\text{theoretical power (kW)} = f \times s_m \times n_{sec}$$

where f = force on piston (kN)
 s_m = length of stroke (m)
 n_{sec} = number of strokes per second

If the pressure is measured in bar and piston area in m²

$$f = (\text{bar} \times 10^2) \times (\text{cross-sectional area of piston})$$

Losses of energy due to friction in the working parts and pipes, leakage of the valves, etc., may cause very low efficiencies. Thus, whereas carefully designed and constructed pumps may have efficiencies up to 90%, the efficiencies of small farm models, owing to their imperfect construction, generally range from 20% to 75%.

The limiting height or pressure at which water can be delivered by pumps is determined by (1) the power available; (2) the absence of leaks in the valves; (3) such

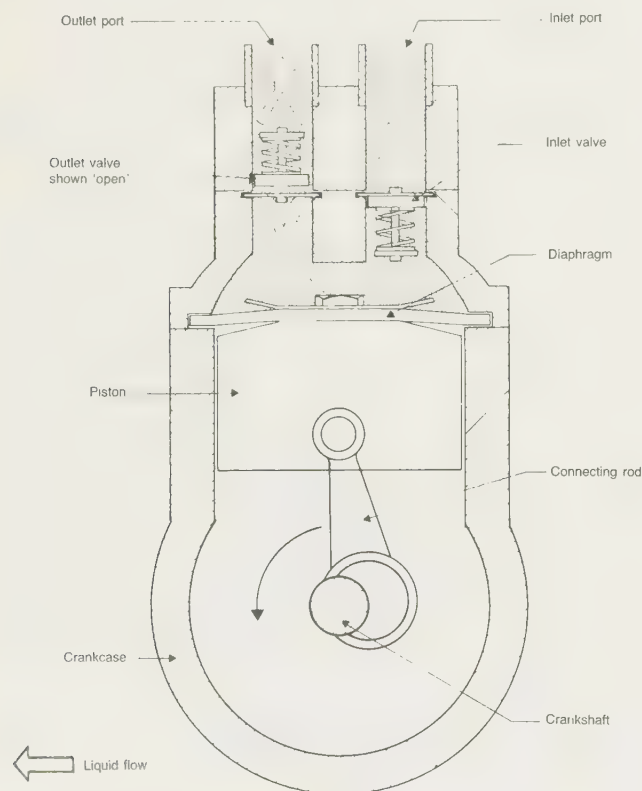


Fig. 10.5 Section through single chamber of diaphragm pump of general type used in field-crop sprayers. (Crown copyright)

details as the fit of the piston in the cylinder; and (4) the strength of the materials. In theory the quantity of water delivered is independent of the head, but in practice the 'volumetric efficiency' (i.e. the ratio of the actual volume discharged to the plunger displacement) falls off at high heads, and it is advisable when selecting a pump to know its capacity at various heads.

The manometric head is the sum of the static head (the vertical distance from the lowest pumping level to the highest point of delivery) and the friction head, representing all friction losses. The friction losses per 30 m (100 ft) of various sizes of piping are given in Table 10.1. Where there is an appreciable bend in the pipe, each bend produces a friction loss equal to 7.5 m (25 ft) of straight pipe of the same diameter. Where a pressure tank is used, about 6 m (20 ft) must be added to the head. It should be pointed out that water pipes invariably deteriorate with increasing age, and this deterioration may sometimes be rapid. In cases of doubt, a slightly larger size than that indicated by the table should be chosen.

Aluminium portable mains, PVC (Class D) pipe and asbestos cement underground mains are commonly used

Table 10.1 Friction losses in pipes (Imperial units)
approximate loss of head when water is rassed through 100 ft
of galvanised iron piping

Gallons per minute	Loss of head (ft)				
	Inside diameter of pipe (in)				
	1	1½	2	3	4
2	0.85	0.11			
3	1.8	0.23			
4	3.1	0.40			
5	4.8	0.60	0.14		
6	6.8	0.86	0.20		
8	11.6	1.5	0.36		
10	17.9	2.3	0.54		
20	65.0	8.5	2.0	0.24	
30		18.0	4.3	0.52	0.13
40		32.0	7.5	0.90	0.22
60		68.0	16.0	2.0	0.47
80			28.0	3.4	0.82
100			43.0	5.4	1.28
150			95.0	11.6	2.70
200				20.0	4.6

for irrigation schemes; high flow rates are sometimes needed, and manufacturers readily provide information on suitability for specific purposes and friction losses.

Choice of pump

For farm pumps the absence of operating troubles and cheapness in first cost are usually considered to be of more consequence than the highest mechanical efficiency.

For shallow wells the choice generally lies between the horizontal piston pump and the simple centrifugal type, and for deeper wells, either the vertical plunger type or a submersible centrifugal may be used. Piston pumps usually cost slightly less to run than centrifugal but the latter are less subject to mechanical troubles and are generally to be preferred where there is sand or grit in the water.

When a new pump is installed on a medium-sized dairy farm it ought, if possible, to be capable of delivering up to 1800 l (400 gal) per hour at a pressure of about 50 psi (3.45 bar). It is often expensive to secure a good pressure by use of a high storage tank, and a pressure tank with automatic control is normally preferable where an electric drive is employed. Electric motors are ideal power units because of the ease of arranging an automatic control, but where electricity is not available a diesel engine or a windmill may be used.

Irrigation

Overhead irrigation is now successfully employed by many vegetable growers, to assist in the production of high-value crops such as cauliflower, lettuce, onions, tomatoes, etc. It is used for watering-in the plants, and for maintaining a luxuriant growth in times of drought.

Experiments have shown that where water supplies are readily available, the irrigation of farm crops such as sugar beet, potatoes and grassland can also be economic, especially in the drier regions of the South and East. Unfortunately, water supplies are limited, and seem likely to restrict the extension of the practice. When water is available, deciding what crops to irrigate and when to apply the water is no simple problem in Britain, on account of the vagaries of the climate. As a general rule, farmers and growers judge by experience, rather than by any scientific method, when water is needed. In a dry

spring or summer, vegetable growers usually keep the irrigation equipment going more or less continuously during the day, and apply the water to the crops which they think will produce the best return. With fruit and vegetables, much depends on marketing, and it is impossible to formulate definite rules. Scientists have, nevertheless, studied the problem from the viewpoint of producing maximum crops, and have evolved a method which involves a study of the weather records for the particular area during the immediately preceding period. The method is explained in a Ministry of Agriculture publication.

Where a good water supply is available the equipment used generally consists of a fairly powerful engine (a tractor is often used, but an electric motor in conjunction with a pressure tank and automatic switch gear is ideal), a good pump (often of the centrifugal type), delivery pipes and equipment for distribution. The object is to apply the water evenly and not too fast, giving the equivalent of about 25 mm (1 in) of rain in 3–4 hours. It is always advisable to give a good soaking – not less than 12.5 mm ($\frac{1}{2}$ in).

The introduction of labour-saving irrigation machines and operating systems, coupled with a somewhat higher than average proportion of dry summers has resulted in a continuing increase in irrigated area in Britain. The results of an official survey of practice in England and Wales in 1983 are given in Table 10.2, and briefly summarise the position concerning crop areas and amounts of water used.

Table 10.2 Main crops irrigated, areas and water use in England and Wales, 1983* (approximate figures)

<i>Crop</i>	<i>Area irrigated (ha)</i>	<i>Water use (million m³)</i>
Potatoes	31 000	20.0
Sugar beet	16 000	8.3
Grass	16 000	10.0
Vegetables	15 000	6.8
Cereals	15 000	5.0
Fruit	6 500	4.1
Other	4 000	1.0
Total	103 500	55.2

* MAFF (1983) *Irrigation of Outdoor Crops, England and Wales, Special Enquiry*. STATS 217/83.

Choice of equipment

The basic systems of distribution employed in Britain are (a) spray-lines, (b) small-diameter rotary sprinkles and (c) large-diameter rotary sprinklers. Spray-lines are usually chosen where it is necessary to irrigate only vegetable crops, while large-diameter sprinklers are used mainly on such crops as grass, bush and top fruit, and coarse vegetables. Small-diameter sprinklers have some of the merits of both of the other systems, being fairly easily moved, and capable of applying the water in small droplets. Mobile equipment may use a large rotary rainer, a number of rotary sprinklers mounted on a non-rotating boom or sprinklers on a large rotating boom.

Many factors are concerned in choice of equipment, and since several of these are interrelated, details need careful study. When the type of distribution equipment has been decided, it is necessary to determine:

- (1) Maximum area to be covered at any one time. This will depend on the total crop area and also on the application rate.
- (2) Type of pump. This will depend on pressure required at the nozzles, and this in turn is influenced by the type of distribution equipment.

In order to work out details of the pump performance required it is necessary to calculate the total head against which the pump must work. This is the sum of:

The suction lift.

The static head (vertical distance between the pump and the highest delivery point).

Friction losses due to delivery pipes (see p. 171), valves and bends.

Pressure head required at the nozzles.

The pressure head required will usually be in the region of 30–50 psi (1.87–3.45 bar), but large rainers may need up to 80 psi (5.5 bar). Pressure head in psi is converted into ‘feet of head’ by using the factor

1 psi = 2.31 ft head of water

When the total head and throughput are known, the water horse-power is easily calculated, and from a knowledge of the pump efficiency the theoretical engine horse-power is obtained (see p. 170). If an electric motor is



Fig. 10.6 Pto-driven centrifugal pump drawing from butyl-lined reservoir and pumping into portable irrigation main. (Wright Rain)

used the size needed corresponds closely to the calculation, but with any type of internal combustion engine it is advisable to allow a considerable margin above the calculated power. In the case of small units, the size of engine needed for satisfactory continuous running is about 50% above the calculated need.

An advantage of the centrifugal pump, which makes it particularly suitable for irrigation, is the fact that it automatically accommodates itself, within limits, to variations of head and quantity. In practice, both head and quantity often vary widely when a large irrigation plant is operated over a number of different fields.

Management of pumps

Pumps must never be started or run 'dry'. Some have an automatic cut-out device which shuts off the engine or motor if delivery fails. In most pumps, a small amount of leakage at the glands is a normal occurrence, and no attempt should be made to eliminate leakage completely by over-tightening the glands. Pumps differ widely in lubrication requirements, and the manufacturer's instructions should be carefully followed. It is important to drain the pump completely in frosty weather.

When water is drawn from a stream an efficient filter must be used in order to avoid trouble both in the pump and at the nozzles. A delivery valve should be incorporated in the delivery main near the pump, in order to permit the load to be taken up gradually.

Distribution systems

The delivery pipes may be portable, of light metal, with quick-coupling connections. Some growers prefer to lay permanent underground mains to every suitable field, and to install stand-pipes at intervals along the headland, so that only the sprinkler lines need to be moved.

Oscillating spray lines: spray lines normally consist of 39–50 mm ($1\frac{1}{2}$ to 2 in) diameter pipes, carried on light steel chairs, and having jets every 0.6 m (2 ft) along the line. The spray line may be automatically oscillated through an angle of about 90° by a device fitted at one end, and operated by the water flow. Some users, however, prefer to throw the water all in one direction and to



Fig. 10.7 Sprinkler nozzle with two jets. Mechanism is operated by long-range jet on the left. (Wright Rain)

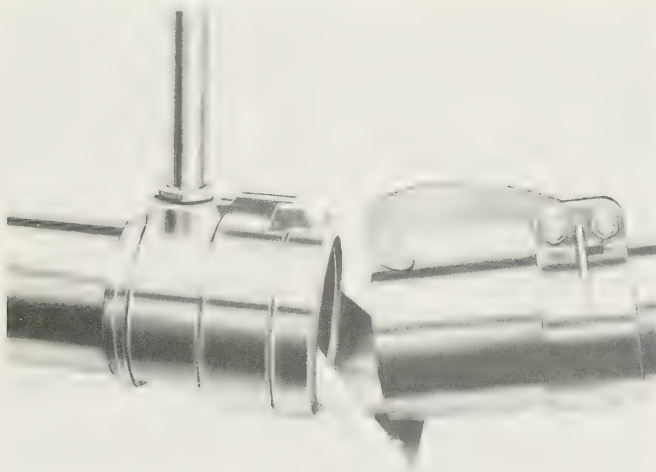


Fig. 10.8 Automatic connector for irrigation pipes.
(Wright Rain)

change angles by hand. A pressure of 30–50 psi (1.87–3.45 bar) must be maintained at the jets, and with the oscillating line a lateral throw of about 12 m (40 ft) is generally obtained. The length of spray line that can be operated naturally depends on the capacity of the pump, size of the delivery pipe, distance from pump to spray line, etc. A length of 183–275 m (200–300 yd) is fairly common.

Light, portable *rotary sprinkler* lines are now widely employed in many countries, both in humid and arid regions. Equipment of this type is employed in Britain, both for farm and horticultural crops. The sprinklers are slow-rotating (usually 1 rpm or less) and cover a circle varying in diameter from 18–30 m (60 to 100 ft). The sprinklers are carried on risers attached to aluminium piping, usually at intervals of about 9–15 m (30–50 ft), with sprinklers having an effective throw of 12 m (40 ft) a suitable spacing for a square layout is $0.6 \times \text{diameter} = 15 \text{ m}$ (48 ft). In practice, however, it is a sound arrangement to space the sprinklers closer (e.g. at 11 m (35 ft) intervals along the line) and to space the laterals wider at $0.7 \times \text{diameter} = 17 \text{ m}$ (56 ft). Such an arrangement produces a considerable overlapping of patterns and results in a reasonably even distribution, with relatively few moves. A line with eleven sprinklers at 11 m (35 ft) spacings which is moved 17 m (56 ft) at a time will water an area of $(11 \times 35 \times 56)/43\,560$ acres, i.e. 0.2 ha



Fig. 10.9 Self-sealing bayonet-type standpipe coupler to facilitate moving of sprinklers. (Wright Rain)



Fig. 10.10 Self-move irrigator with 12 small low-pressure flood-jets giving 36.6 m (120 ft) width of application with maximum bout length of 900 ft (272 m) using a 38 mm (1½ in) supply pipe. Winching can be by machine's own turbine or by auxiliary engine. Equipment is suitable for distribution of slurry 'filtrate'.

($\frac{1}{2}$ acre) approximately. If each nozzle delivers 5 gal/min, the total water delivered is $5 \times 11 \times 60 = 3300$ gal/hour.

Since 25 mm (1 in) of water is equivalent to 22 622 gal/acre, the application rate is approximately $3300 \times 2 / 22\,622$ in/hour, i.e. just under 7.6 mm (0.3 in)/hour.

The success of such a system depends on having very light aluminium pipes which are connected up or disconnected very rapidly either by means of lever-operated fasteners or simply by partially rotating the pipe – a movement that can be made while holding the pipe at its point of balance. Rubber seals are provided in the pipe ends, and these allow flexibility which permits the pipe-lines to run easily over undulating land.

Moving of irrigation lines requires a good deal of labour, often at a busy time, so methods of using equipment which minimise this work are sought. The use of selfsealing bayonet-type standpipe couplers in conjunction with sprinklers having a long throw makes it practicable to move sprinklers rapidly without moving the lines. Each sprinkler line has twice as many standpipe couplers as sprinklers; and when irrigation begins, sprinklers are fitted

only to alternate couplers, so that the watered circles are just meeting. Half-way through the application, each of the sprinklers is quickly changed over to the adjacent coupler, and by this method a uniform application can be achieved and the movement of the sprinkler lines can be reduced to once daily.

Large-diameter sprinklers (rainers) have the advantage that moving can be quickly done, since a single large rainer will distribute the output from a fairly large engine and pump. With long risers they can work effectively in types of orchards where moving sprinkler lines may be difficult. The large jet is capable of handling dirty water, but the pump needed for effective distribution must be a high-pressure type.

Use of plastic spray lines

For application of irrigation on a small scale it is possible to apply water effectively by means of plastic pipes. For example, pipe made of polyvinyl chloride, with diffuser nozzles welded to it, can be used for irrigating grassland, orchards, etc. The pipe is flat when empty, and about 50 mm (2 in) in diameter when used at about 10–20 psi (0.7–1.4 bar) working pressure.

Alkathene tube of 25 mm (1 in) bore can also be used, without nozzles, the holes being pierced by means of a punch about twice the diameter of the hole required. Size of punch can range from about 1.5–3 mm ($\frac{1}{16}$ – $\frac{1}{8}$ in) diameter, with about three holes per foot (10/m). A good water pressure, e.g. 1.7–3.5 bar (25–50 psi), is desirable.

Self-moving irrigation equipment

Moving pipe-lines and sprinklers in arable crops which have just been watered is heavy and unpleasant work that often interferes excessively with other urgent jobs. There is a wide choice of self-move systems which can easily justify their cost where irrigation is regularly practised on high-value crops or on an extensive scale. Principal types include:

Portable hose-reel and moving rainer: The hose-reel carrier remains stationary during work. The rainer is carried on either a light wheeled trolley or a sledge, which is first pulled by tractor away from the reel carrier, until the hose is fully unwound or the end of the area to be

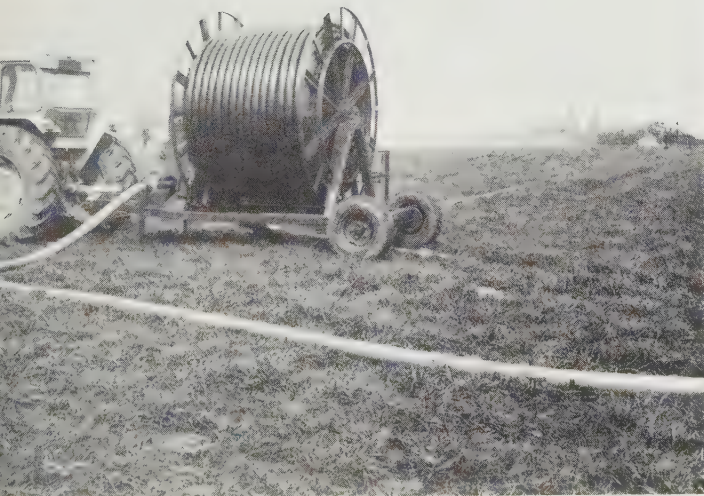


Fig. 10.11 Portable hose-reel with 300 m of 90 mm diameter hose, pto-driven booster pump and automatic hose layer, operating with four-wheel travelling rain-gun at effective bout width 74 m. (Ardleigh-Swift)

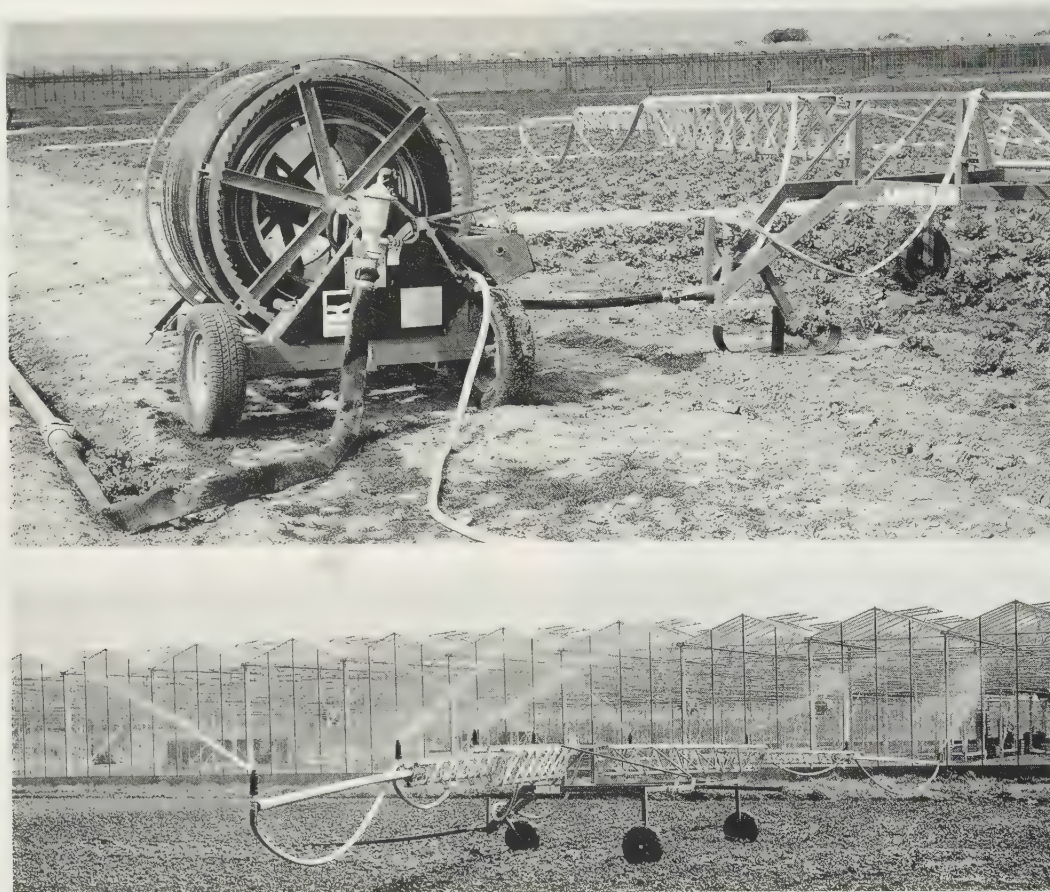


Fig. 10.12 Hose-reel-operated telescopic travelling sprinkler booms. Lightweight welded aluminium sections form telescopic spars on each side: these hinge at centre for road transport. The three-wheeled adjustable track-width trolley closes to give

2.4 m overall width on the road. (*Javelin/Irrifrance*)

Above: Close-up of hose reel, trolley and boom sections.

Below: Turbine sprinkler jets used for medium application rate on the same boom.

watered is reached. During work the rainer is steadily pulled towards the carrier and the hose is wound on the reel by a drive that should ensure a constant speed of travel. On one type, suitable only for a high-pressure water supply, the reel is driven by the water, and no tractor drive is needed during work. Another type has a tractor-operated pump on the hose-reel, and this can be used with a low-pressure water supply or for handling liquids such as slurry (Fig. 10.11).

The rainer is normally pulled to the reel by the high-tensile hose. An automatic cut-off is provided. For general use it is necessary to choose an advanced type of rainer

which can ensure a reasonably even spread over a limited width. With row crops a straight pull helps to avoid crop damage. An automatic device to ensure an even feed of the hose on to the reel is essential: some machines incorporate a refinement to move the whole reel sideways as it rotates, so keeping fixed the point at which the hose joins the reel.

Moving hose-reel and sprinklers (e.g. 'Rainamatic'): A wheeled carriage carries a fixed boom with sprinklers along its length. There is a hose-reel on the carriage, and the machine winches itself towards an anchor near the



Fig. 10.13 Semi-automatic centre-pivot irrigation system in use in potatoes in Eastern England. After setting up no further manual work is normally needed before harvest. (Wright Rain/Farrow)

supply point, winding up the hose as it goes. The number of sprinklers may range from 2 to over 20. In a variant the drive is by traction-tyred wheels on the moving trolley (see Fig. 10.10).

Moving pipe-line with sprinklers (e.g. 'Rainspray'): The line, which may be up to 400 m long, is carried on large-diameter skeleton wheels. The line remains stationary while the sprinklers are operating, and is only moved when empty. The stiff main acts as a torque-tube which is

rotated by a portable engine carried on four wheels, usually at the centre of the line. The tube drives all of the wheels, which have drive strakes fitted to their rims. The whole width of most fields can be irrigated in one bout if the water supply is adequate. Such equipment can work well in row crops such as potatoes.

Rotating boom with sprinklers: The vehicle, usually a tractor, normally remains stationary during operation of the sprinklers. The mobile rotating boom carries a number

of jets and covers a very large circle with droplets of a size comparable with those produced by rotary sprinklers. A typical tractor outfit has a boom spanning 40 m (130 ft) which is raised and lowered by the tractor hydraulics. This wets an area 100 m (325 ft) in diameter and gives effective application of 25 mm (1 in) in four hours on approximately 0.5 ha ($1\frac{1}{4}$ acres). Discharge is 40 m³/hr (145 gal/min), and the outfit can be fed from a typical 75 or 100 mm (3 in or 4 in) main. The tractor is fitted with pipe racks to carry extensions for the portable main, and is best moved by two men: one drives the tractor to its next position, while the other collects or lays the portable main. This type is not best suited to the climate and topography of Britain.

Automatic irrigation

Centre-pivot system: The centre-pivot system is designed primarily for extensive farming in very dry regions. A hydrant supplies a well braced lattice boom which rotates as a radius arm about a central tower, and has electric motor drives to the wheels of a substantial outer support on the circumference and also to those of intermediate supports. Spacing and outputs to sprinklers are related directly to the area to be watered at each radius, and drive to each set of wheels is automatically regulated from the central power to keep the line substantially straight. Very large circles of over 70 ha can be watered.

Automated centre-pivot equipment can be more adaptable to large areas of root crops such as potatoes than may seem likely on first examining the system. Though operation is appreciably easier on flat land than where there are irregular undulations, it is claimed that slopes up to 30% can be successfully worked. In large square blocks of land a corner system consisting of a special folding arm can be attached to the outer end. The movement of this arm at the correct points can be controlled by radio signal picked up from a buried cable. A simpler way of dealing with awkward corners may be by independent 'solid set' stationary sprinklers.

Linear machines: Linear irrigation machines are designed to move in a straight line over rectangular areas comparable in size with those served by centre-pivot systems. The lattice booms carrying sprinkler nozzles are supported on pairs of wheels driven by individual electric motors.

Power in the field is normally provided by a diesel electric generator on the main four-wheeled mobile end tower at the supply end of the irrigation line. This tower also carries a fuel tank and the main control panel; it has a suitable connection with the water supply. Application tends to be restricted to areas where the land is of good quality, flat, and laid out in rectangular fields of convenient size (Fig. 10.14).

Important design decisions concern area to be watered simultaneously and connection of the mobile power unit to the water supply. A simple solution applicable to fairly small areas involves the use of a length of pressurised flexible hose; in a particular system (e.g. Valmont Model 9450) the power unit and line can travel 225 m before re-coupling to the stationary supply main is necessary.

In a more complex automated system developed in the USA primarily for world-wide use in arid areas (e.g. Valley Linear II), the mobile tower has two coupling heads, each mounted on two-wheeled carriers which are flexibly linked to the main tower, and operate one ahead of and one behind it. The buried main has risers every 44 ft along it, and automatic electro-hydraulic coupling and disconnection of the two heads ensures that a newly connected head starts working as the other is disconnected.

Use of hydraulic sequence valves in conjunction with a 'solid set' irrigation layout can provide automatic watering on a round-the-clock basis or at particular times of the day. The valves, fitted between main and sprinkler, are operated by releasing and restoring mains pressure. As line pressure is released a spring moves a piston down a cylinder, and the return stroke, when pressure is restored, operates a ratchet cam wheel. Different cam wheels are available to open the valve at frequencies ranging from once in every second cycle up to once in 24 cycles.

Frost-protection sprinkler systems

These are usually designed for British conditions to apply about 3.2 mm ($\frac{1}{8}$ in) per hour to protect fruit crops against radiation frosts of up to 10°F (5.6°C). Since it may be necessary to apply water for about eight hours on each of several succeeding nights when the soil is at field capacity, the area must be well drained. The sprinklers are designed to rotate at about 1 rpm to avoid freezing on the crop. Alarms for manually operated equipment are set to give a warning at a temperature of about 33–34°F (0.6 to 1.1°C). Automatic systems start up at 0°C. On land where



Fig. 10.14 Field-scale linear irrigation unit with flexible hose connections working in potatoes at Gleadthorpe Experimental Husbandry Farm. (*Rand/Valmont*)

the height of sprinklers varies considerably, pressure regulators may be fitted in each sprinkler standpipe to avoid uneven distribution. A typical orchard of 8 ha (20 acres) requires a pump output of about $230 \text{ m}^3/\text{hr}$ (850 gal/min).

Equipment for pipeline distribution of liquid manure

A pump specially designed for delivering liquid manure to rainers is a multi-cylinder piston type in which the poppet valves will handle a considerable amount of straw

without blocking, and can be removed in a few seconds for cleaning out when this is necessary. A simple relief valve is incorporated in the delivery chamber.

The delivery head of such pumps can be up to about 90 m (300 ft).

Centrifugal pumps for handling slurry use a simple impeller with more clearance than those used for pumping pure water. Delivery head is limited (generally not over 55 m (180 ft), but is usually sufficient for distribution on fields within about 0.4 km ($\frac{1}{4}$ mile) of the tank, provided that the fields are not considerably higher. Slurry needs to be diluted by at least 2:1 and preferably 3:1 for

effective pumping, and where fibrous materials such as hay or silage are included in the slurry it is advisable to use a mixer-cutter to transfer it to the storage tank or to the main pump.

When a piped distribution system for slurry is laid out it is essential to employ valves to shut off any parts of the main that would constitute a dead section. Thus, when a lateral is fed half-way along a main, the far end must be shut off, otherwise the head end will gradually fill with sediment until the pipes are completely blocked. It is also advisable, wherever practicable, to arrange the pump so that it can deliver pure water for a short time after the manure tank is emptied. This cleans out the pipes and the rainer, and helps to wash the manure off the herbage, thus avoiding scorch and some of the adverse effects on palatability.

Rainers for dealing with slurry need a fairly large aperture – minimum about 9 mm ($\frac{3}{8}$ in) diameter. A type that is particularly suitable for handling slurry uses an aperture made of rubber, which can stretch to avoid blockage.

With effective separators available there are good reasons for separating the solids and using simple systems for liquid distribution. Mobile equipment has particular advantages owing to the unpleasantness of manually handling the equipment after slurry has been distributed. The need to avoid atmospheric pollution near villages makes it likely that hose-reel-operated rainers will be replaced by equipment such as mobile booms with dribble-bar outlets in such areas.

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Forage Harvesting: Cutting and Swath Treatment

Most British farmers who have cattle or sheep enterprises rely to a greater or lesser extent on conserved green forage crops for winter feeding. Hay remains an important conservation method in terms of total production, but silage making continues to increase, and is the main or only conservation method employed on many intensively managed farms.

Whatever the method of conservation, forage crops have first to be cut. After this they may be treated to speed natural drying, or may be carted for processing or storage. This chapter mainly deals with cutting and swath treatment whether it be for hay, silage or dried grass. Equipment particular to silage-making and feeding, hay-making and artificial drying techniques is dealt with in Chapters 12, 13 and 18 respectively.

Mowers

Finger-bar mowers did not change in principle from the days in the late 19th century when horses were used to pull them, up to the second half of the 20th century when they were fairly rapidly superseded by tractor-operated rotary machines. There are still a few reciprocating machines used on small family farms, especially in mountainous conditions, for both forage and grain crops, mainly on the basis that the reciprocating type is lighter and more appropriate for use with low-powered, often pedestrian-controlled two-wheeled tractors. When a British Standard for the more important details of the reciprocating finger-bar mechanism was published in 1973 (BS 1562) it achieved little more than indicate British and North American inputs by setting the standard width of a single knife section at 76.2 mm (3 in) and not 75 mm. The later ISO R 563 standard was concerned only with knife sections, and the main application of the

cutter bars using such knives is now in combine harvesters and arable crop windrowers rather than grass mowers. Reasons for this are varied but a main cause of the rapid change to rotary mowers for grass and forage crops has been general acceptance of technical success of high-speed rotary mowers in cutting the dense grass and other lush green crops now grown for silage, associated with the need for swath treatments of kinds that can result in rapid drying in good conditions, ability to withstand some rain, and in some cases ease of picking up by forage harvester without the need for extra spreading or windrowing operations.

Editions of this book from the 1940s to 1960s noted progress in adapting finger-bar mowers to use by increasingly powerful tractors by lengthening cutter-bars and improving drives: substantial improvements were made in power transmission by getting rid of all unnecessary unbalanced forces in the reciprocating cutter-bar drives; but the advent from the 1950s onwards of mowers and harvesters with rotary knives or flails soon indicated that

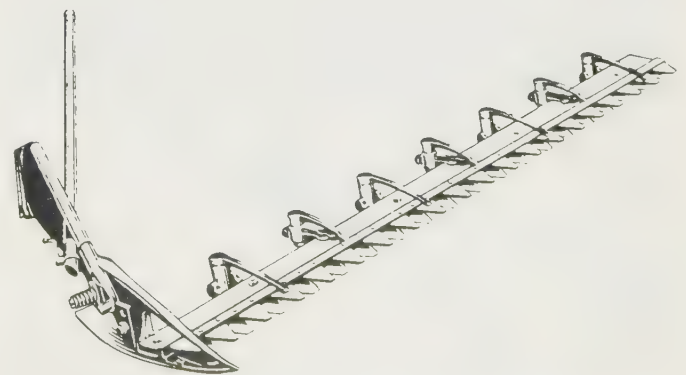


Fig. 11.1 Double-knife (fingerless) cutter-bar. (*Busatis*)

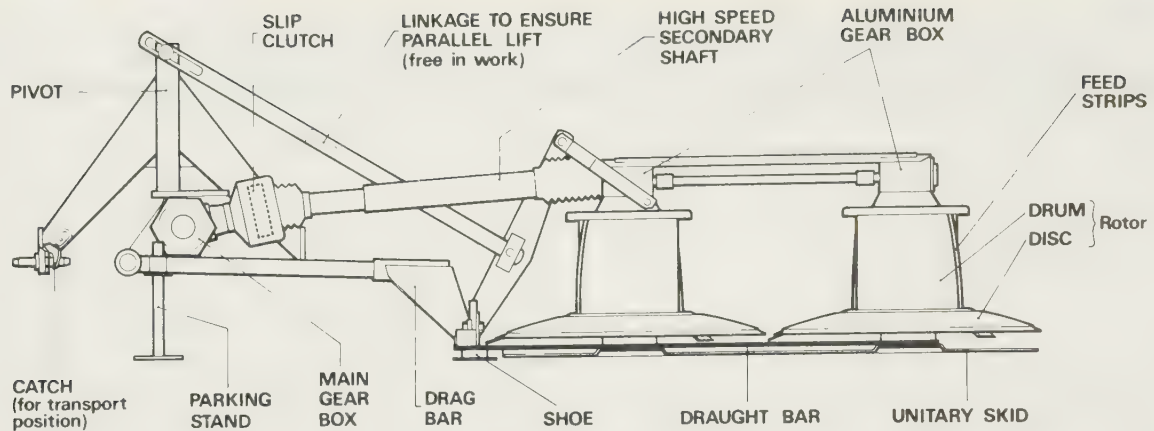


Fig. 11.2 Main design features of early tractor mounted two-drum mower with top drive by shaft and bevel gears. (Massey-Ferguson)

Weight of the rotors is supported by the draught-bar, to which are attached skids for cutting-height control.

rotary mowers could revolutionise grass and forage crop harvesting, by eliminating most of the hard work, especially where the main effort was switched from hay to silage.

This preamble leads inevitably to a decision to glance only at double-knife (finger-less) cutter bars before turning to the main subject of rotary mowers and mower-conditioners.

One of the easiest methods of achieving a dynamic balance in a reciprocating mower is by driving two exactly

similar knives in opposite directions. In the Busatis double-knife cutter-bar, there are no fingers. Two similar knives are located one above the other by spring-loaded oscillating pivot arms. Both the pivot arms and the knife connections operate through sealed ball joints. Individual knife sections move over each other exactly like a pair of scissors. There is a fairly wide spacing between adjacent sections on each knife, and this makes it easy to sharpen the knives correctly. The fast operating speed helps to protect the knives from damage by throwing stones off the points. A high standard of maintenance is required to secure a good performance.

The double-knife system lends itself to use as a light-weight hydraulically driven front-mounted mower on low-powered tractors; swather discs at each end of a 2.25 m (7 ft 6 in) cutter-bar direct the swath between the tractor wheels. Power requirement of about 5 kW is within normal external hydraulic capacity of modern small tractors, and the swath can easily be treated by rear equipment or picked up by forage wagon.

Rotary grass cutters

The mowers included in this section are those which have knives rotating about a substantially vertical spindle.

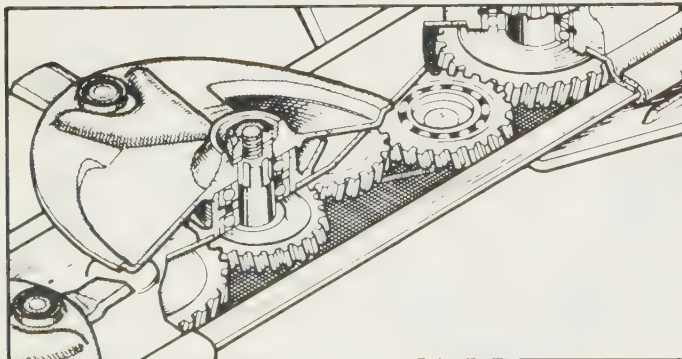


Fig. 11.3 Drive to mower discs by gears running in an oil bath. (Kuhn)

Rotary mowers used for conservation are of two main type: drum mowers driven from the top, by shaft and gears or by V-belts; and disc mowers which have the cutting mechanism driven by gears housed in a slim casing below the knives. The knife carriers of drum types tend to be of larger diameter than those of disc mowers. Single-rotor types, usually 1.5–1.8 m (5–6 ft) wide, are used primarily for trash-clearing work rather than for forage conservation. These latter are included in Chapter 22.

The rotors of drum and disc mowers can be arranged in contra-rotating pairs. The chief advantages of rotary mowers are ability to work at a high forward speed and the fact that the cutting mechanism is very free from blockages and leaves a light swath which has not been chopped into short lengths. Power requirement is high compared with that of finger-bar mowers and purchase price is also considerably higher. For grass cutting in Britain these disadvantages are readily accepted.

A simple two-drum mower has three double-edged cutting knives on each drum. Drive to the drums is usually by V-belts to a primary gear-box from which a horizontal shaft drives the drums through bevel gears. Gear or toothed belt final drive allows knives on adjacent drums to overlap without interference. Cutting height of drum types is regulated by the rotating saucers attached to the bottoms of the drums. Drum mowers much over 2 m wide tend to be heavy, and of trailed type. The cutting heads may be suspended from the frame via heavy-duty springs which take most of the weight and allow the saucers to follow ground contours more easily. In some designs two cutter heads are carried at either end of a beam via a centre pivot.

Mower engineering developments

Much of the mower engineering development effort in Britain since the 1970s has been concerned with combined mowing and swath treatment machines, and much of this chapter deals with developments in this field in both Britain and Europe. It is, however, convenient to look first at recent developments in disc mowers. A new disc cutter bar of narrow wedge shape developed by *VICON* has triangular three-bladed discs and cutter-bar skids adjustable to provide for required stubble length. A new hydro-pneumatic flotation system can be adjusted to limit ground pressure; and pressure gauges above both wheel

assemblies indicate levels of skid pressure exerted. The cut crop is raised into the machine's windrow-forming system largely by air flow developed first by the cutting rotors and secondly by a high-speed (1400 rpm) centre delivery auger which includes a central rotor carrying radially arranged corrugated metal combs which run beneath the crop during delivery through adjustable rear doors (Fig. 11.4).

The model illustrated has a cutting width of 2650 mm (8 ft 8 in), and typical windrow widths are 1000–1650 mm (3 ft 5 in–5 ft 5 in). The basic design philosophy is



Fig. 11.4 Eight-disc mower of working width 3.18 m with new design narrow wedge-shaped cutter bar carrying triangular three-knife discs arranged to produce a powerful upward air flow. The cut crop is delivered to a high-speed centre-delivery auger rotating at 1400 rpm and producing a powerful air-flow to assist crop conveying. Delivery to the windrow, regulated by adjustable rear doors is by a cylinder of radial fan-type blades built into the centre of the auger. Corrugated bolt-on blade edges work beneath the crop and are designed to produce a stable box-shaped windrow which lies lightly to assist rapid drying and shed light showers. (*VICON ZM 322 Swather*)

that major requirements include a very smooth cutting action, an air-borne flow of cut crop through the machine, and production of a rectangular-shaped windrow with a laminated structure that allows a free flow of air through it and is reasonably durable in showery conditions.

The fairly basic machine illustrated (Fig. 11.4) is equipped with Vicon's widely used Full Swivel Hitch providing power drive when cutting square corners. A hydraulic steering cylinder to regulate drawbar angle from the cab is an option. Larger models include a wide centre-pivot version with in-cab control of drawbar angle and arrangements for end transport on highways.

Engineering of drum mowers

A good example of advances in the engineering of drum mowers by specialist European manufacturers is the CM 265A 4-drum machine by PZ (Zweegers) (Fig. 11.5). This machine of unique design has large outer drums of 900 mm (3 ft) diameter and two inner ones of 400 mm diameter. The large drums rotate inwards and the small outwards to form two swaths initially; and the two can be brought together neatly by two adjustable rotary windrow



Fig. 11.5 High-capacity four-drum rotary mower with two large-diameter outer drums rotating inwards and two smaller diameter inner drums rotating outwards, initially forms two swaths which may be moved alongside one another by two adjustable rotary swath formers if required. The mower in work is attached to the drive at a wide angle which can be reduced while mowing by use of in-cab finger-operated hydraulic control. This makes it easy to avoid obstacles, take less than the maximum 2650 mm cutting width or move completely out of crop prior to folding end guards and raising for road transport. For measurements see text. (SKH/PZ (Zweegers) CM265A)

formers if desired for immediate or early pick-up by forage harvester or baler. Cutting width is 2650 mm (8 ft 8 in) and typical windrow widths 1000–1650 mm (3 ft 5 in–5 ft 5 in).

Floating of the drums is assisted by extension springs and mounting on trailing arms to lighten the load on the freely revolving saucers below the knife discs. Minimum pto power need is reasonable at 37 kW (50 hp). The mower in work is attached to the tractor at a wide drawbar angle, and can be moved sideways hydraulically by in-cab finger-tip control of the drawbar angle ram. This makes it easy to cut round obstacles such as trees.

The mower can be raised out of work by a single-acting hydraulic cylinder for maximum ground clearance at headlands and in transport. Transport width with the machine centred behind the tractor and end safety guards folded is 2850 mm (9 ft 4 in).

A four-drum centre-drive unit with Y-shaped metal conditioner fingers for swath treatment and windrow formation (Niemeyer, Fig. 11.6) employs a double-articulated drawbar and drive system initiated from a first pivot located well behind the tractor wheels, to provide for non-stop 180° turns and hydraulic movement of drawbar and drive from right to left and vice versa as illustrated in Fig. 11.6(b). The machine folds to an approximate width of 2.96 m for road transport.

Hydraulic flotation system for drum mower-conditioners

Figure 11.7(a) outlines a basic flotation system developed for heavy two-drum mower-conditioners. Effective application requires a purpose-designed basic chassis with wheels and axles strong enough and suitably designed to raise fairly heavy loads quickly when needed. User experience has proved the benefits arising from minimum scuffing and wear, reduced power need, and a smooth flow of crop through the conditioner, resulting in windrows of good shape and internal structure. A pair of intermeshing contra-rotating nylon brush cylinders has proved a successful swath treatment for silage making.

Figure 11.7(b) shows how a small drum attached below the drawbar of a three-drum mower is accommodated: this drum co-rotates with the adjacent big drum and the crop cut by it joins the swath from the big drum in its passage to the conditioner.

Knives on disc mowers may be carried on oval, triangular or other non-circular carriers, to facilitate folding back of

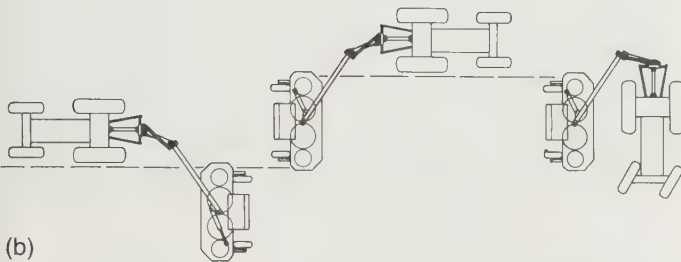
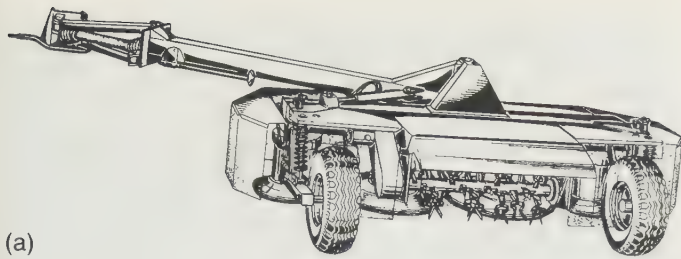


Fig. 11.6(a) High-capacity example of four-drum trailed mower conditioner with small outer drum and large inner drum co-rotating towards the centre on each side. The central multi-speed conditioner has spirally arranged Y-shaped metal tines of spring steel. Speed of rotation can be adjusted by gearbox. (b) The lower drawing illustrates how the central power drive enables the outfit to make a 180° turn at the headlands using a hydraulically activated change-over which swings the drawbar and pto from right to left (or vice versa) during the turn. For transport, hydraulic adjustment of drawbar angle and folding combine to bring transport width down to approximately 2.96 m. (Niemeyer RO 301 GK Mower-Conditioner)

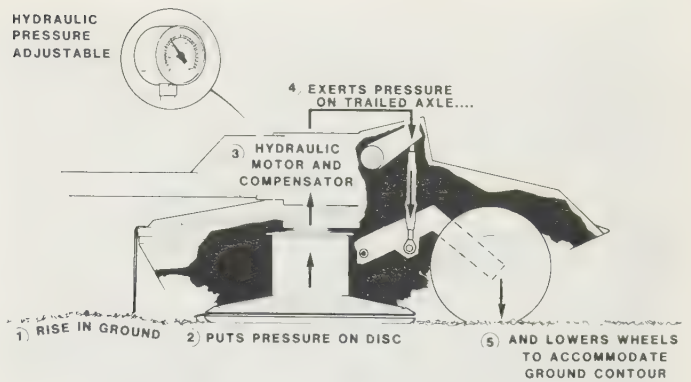


Fig. 11.7(a) Hydraulic flotation system applied to two- and three-drum mower-conditioners. (Kidd Clipper Models 240–2 and 310)

Relevant features include two strong trailed axles equipped with large wheels to carry the machine's weight without excessive sinkage and field compaction. Upward pressure on the large-diameter free-rotating saucers caused by encountering localised high ground raises hydraulic pressure in the flotation system, and this automatically raises the drum through the compensatory system. Sensitivity is regulated to suit conditions by finger-operated pressure control. In smooth conditions standard cutting height is 25 mm (one inch). Additional deeper-dish saucers can be fitted to increase cutting height to 45 mm (1.75 in) in rough conditions.

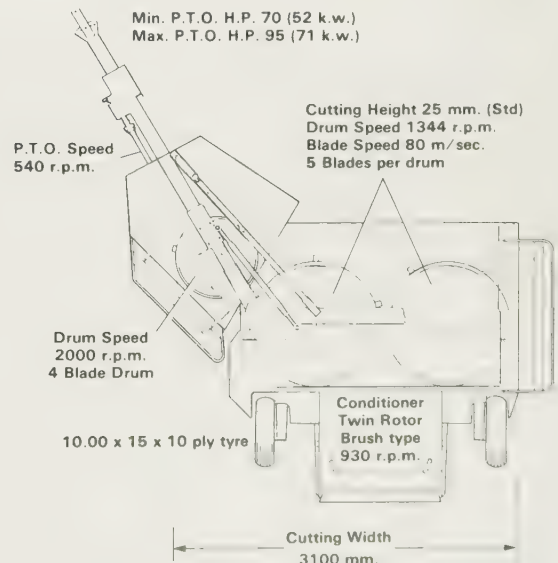


Fig. 11.7(b) Three-drum mower-conditioner with floating smaller V-belt-drive, high-rotary-speed drum attached below swinging drawbar shown held by hydraulic ram in its fixed working position. Adjustment of the ram to transport position moves the hitch to the centre-line of forward travel, reducing transport width to 2.8 m. In work, the small drum has an independent flotation system and deflector plate to ensure accurate flow of crop cut by it between the two large drums to the twin intermeshing nylon brush conditioning rotors. A front drawbar hydraulic ram regulates the vertical angle, providing adjustment of height of cut of the small drum to match that of the large ones. (Kidd Clipper Model 310)



Fig. 11.8 High-powered tractor operating front-mounted and rear-mounted combined drum-and-disc mowers at high speed in a heavy crop. (Watveare/Deutz-Fahr)

knives and crop propulsion. Many disc and drum mowers can be provided with built-in attachments for crop conditioning (*below*).

Machines for swath treatment

When setting out to make hay or wilted silage, the first objective is to remove moisture as rapidly as possible in the swath, the aim being to shorten the field drying time as far as is economically possible. Loss of nutrients begins from the moment the crop is cut, and continues as long as the crop remains in the field. At first, the main loss is due to respiration, but when hay is made, losses in the later stages may include shattering of leaves, leaching by rain, bleaching by sunlight, mould due to long-continued dampness and heating due to bacterial action. In addition to these losses, some of which are difficult to avoid, there are mechanical losses due to the actions of imperfect or incorrectly used machines. For example, if the cutting machine chaffs the crop and the short pieces are scattered over the stubble, there is little chance of harvesting this part of the crop.

Conditioning needs vary widely with climatic conditions: in Britain where drying of forage crops is normally slow

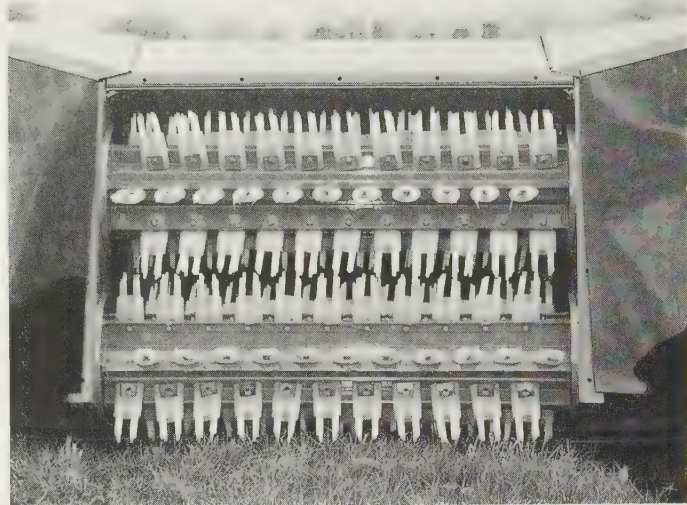
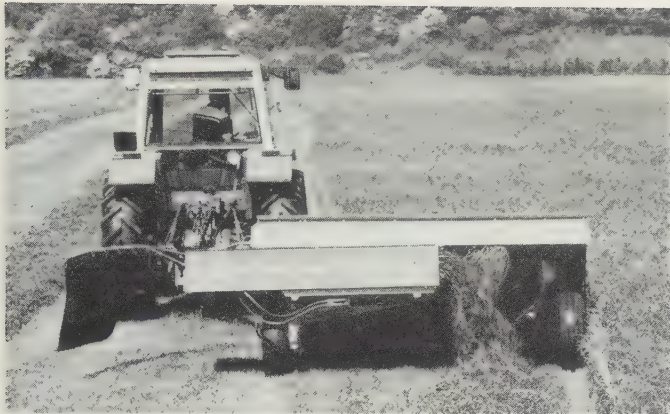


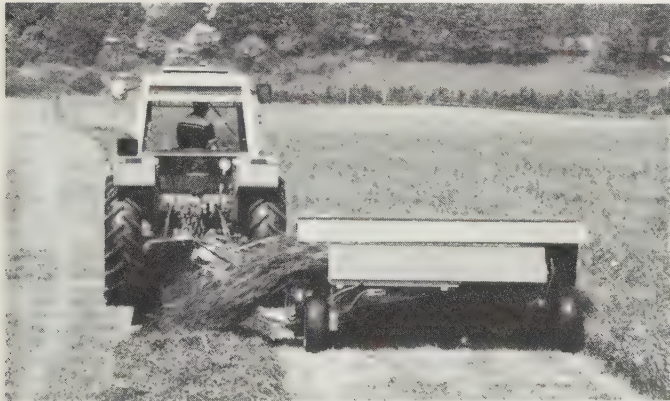
Fig. 11.9(a) View from rear, with hood removed, of two-drum trailed mower-conditioner, showing contra-rotating and intermeshing nylon brush rotors used on model Clipper 240-2. (Kidd)



Fig. 11.9(b) View from tractor cab of work done by Clipper 310 mower-conditioner with small third drum working beneath drawbar and driveshaft and one pair of intermeshing nylon brush conditioning rotors handling the three swaths to form a single windrow for wilted silage (Kidd)



(a)



(b)



(c)

Fig. 11.10 Cutting and conditioning a light ley crop for silage, using Silsoe Research Institute pattern cylindrical conditioning rotor with Y-shaped rubber-mounted metal tines as shown in (c). The 9 ft-cut mower-conditioner has an 'auto-swather' fitted, and adjusted to place two swaths side by side. In (a) the swather positioned to the left lays the first swath near to the uncut crop; in (b) the swather positioned to the right has had its endless belt drive reversed, and delivers the second swath just beyond the first. The electro-hydraulic actions, once set, are automatically repeated. (WestMac/Taarup)

and difficult, controlled experiments have shown the value of early treatments designed to reduce the moisture barrier effect of the crop cuticles without excessive reduction of stem stiffness. The aim is a fluffy uniform windrow which permits mass air movement, enabling easy escape of released moisture to the surrounding atmosphere. Increasing acceptance of the value of early swath treatment for both hay and silage systems, backed up by availability of higher-powered tractors, led inevitably to the conclusion that the normal first harvesting operation should be the use of a high-speed rotary mower-conditioner.

Rotary mower-conditioners

A successful mechanism developed by NIAE (now Silsoe Research Institute) and adopted by several manufacturers consists of Y or V-shaped rubber-mounted tines attached in cylindrical form (Fig. 11.10(c)) to a rotor located just behind the mower drums or discs. The aim is to feed the cut ends of the crop bottom first into the conditioning rotor, which has spokes narrow enough to slip to some extent through the crop and so to rub the stems. A bruising-bar or rough-surface concave retards the crop flow at first, to assist conditioning action by the angled spokes. The rotor then accelerates the whole swath, and the energy is taken out of it by adjustable baffles at the rear of the housing. The objective is a light windrow of rectangular shape, large surface area, and with a good proportion of the lower stems left near the top. Good results with mower-conditioners of this general type depend on providing a reasonable relationship between thickness of the crop layer to be treated and such design and adjustment aspects as clearance between rotor and the stationary conditioning surfaces.

As development progresses, new materials and designs include fingers of nylon and free-swinging mounting of heavier hammers. The aim of surface scratching of the cuticles is further developed by use of flexible plastic bristles in place of steel.

Rotary brush conditioners

Cylindrical rotors fitted with tufts of stiff plastic bristles have been found very effective at providing the type of surface treatment suitable for grassy crops. A factor in ready acceptance of the material is the advantage of



(a)



(b)

Fig. 11.11 Brush type two-drum trailed mower-conditioner with Silsoe Research Institute developed contra-rotating intermeshing conditioning rotors. (*Kidd Clipper 240*)

(a) Working picture shows light rectangular swaths produced by the 1.08 m wide rotors running at 930 rpm when pto speed is 540 rpm.

(b) The brush rotors are seen in the photograph from the rear of machine.

avoiding steel spokes which can become detached and then picked up by a forage harvester. Arrangements which are commercially produced include twin intermeshing contra-rotating brushes which carry the crop between the two rotors (e.g. Kidd (Fig. 11.9(a)) and Agrimech).

The contra-rotating intermeshing nylon brush system has proved to be one of the most effective so far seen for typical UK conditions. The brushes handle the crop gently and with a low power requirement, but the treatment is one of the most effective in scoring or removing much of the



Fig. 11.12 WestMac Taarup front and rear disc mower-conditioners 317E and 307.

Working picture showing front and rear disc mower-conditioners putting a total cutting width of 5.5 m into a single windrow.

impervious cuticle without breaking or appreciably crushing stems or leaves. Results in controlled experiments have been among the best ever, with drying times reduced by up to 55% compared with untreated plots.

Agrimech, on their two-drum mower much used by contractors employ the contra-rotating brush system as an effective conditioner, and has added the option of a side-conveyor belt with in-cab control for making large windrows, in much the same way as the Taarup Auto-Swather illustrated in Fig. 11.10 is used.

It is noteworthy that individual plastic teeth which can be fitted and replaced without the use of hand tools have been adopted by Taarup for use in their front-mounted 'Mowcon' (Fig. 11.12). In view of parallel fitting developments in the grain stripper field, such trends seem likely to be worth study.

Intermeshing notched roller conditioners

A type employing intermeshing rollers with profiled faces of rubber or nylon operates mainly on the crimping principle employed in good drying conditions to avoid leaf loss by speeding up stem drying rate. Used in conjunction with three-blade discs, peripheral speed of the rollers is greater than the speed of forward travel with the aim of thinning out the swath. The rolls are normally set just clear of each other when the machine is operating and no crop is passing through. Pressure can be varied from about 3.1–6.7 kN (700 to 1500 lbf), according to the material being crushed.



Fig. 11.13 A six-disc 3 m-cut mower-conditioner with heavy free-swinging Y-shaped tines and two-speed drive to rotor by interchangeable V-belt pulleys. (John Deere)

When the crop is very heavy, the rolls can be separated a little. The rolls are automatically separated when the machine is raised. Power requirement of a typical machine for dealing with a 2.4 m (7 ft 10 in) swath is in the region of 45 kW (60 hp).

Two-row swathers

Whatever the method of swath treatment, an essential need in silage making is formation of a light windrow of approximately rectangular cross section of the right size for the forage harvester pick-up. With adequate tractor power available, high-capacity forage harvesters often need two swaths put into a single windrow; and a good way of doing this is by use of an 'automatic' two-row swather during cutting and conditioning. Advantages are saving time, opportunity to produce a windrow of good shape, and avoidance of soil and stone inclusion. A type with adjustably automated electro-hydraulic control employs a reversible hydraulically driven heavy-duty belt with nylon slats, and fitted with adjustable deflectors (Fig. 11.10)

The use of mower-conditioners at front and rear of powerful tractors in some ways simplifies the procedure illustrated in Fig. 11.9, where the autoswather is used with a single rear-mounted machine. Figure 11.10 illustrates development of a combination of front and rear disc mower-conditioners to put an effective total cutting width of 5.5 m (18 ft 2 in) into a single windrow.

Requirements include a powerful tractor and installation of a strong T-bracket just above the top-link hitch point of the front-mounted harvester to provide two solid anchor points for right and left check-chains, one on each side. Other basic requirements include strong supports running forward from a triangular Accord type quick hitch built into the harvester at the rear. Rigid points are provided at the front of the machine to which two large extension springs can be connected to assist carrying part of the weight of the mower and to ensure that it is raised over any solid high ground when spring forces and adjustable chain forces are correctly balanced. The geometry is such that the machine in work is in effect pulled from the front. It floats effectively when an upward pull of 40–60 Kgf at the front is enough to raise it without a further push on the front of the spring attachments by the tractor.

Pasture topping and orchard mowing equipment

Some farmers and growers need to carry out regular mowing operations which require the growth of grass or weeds to be cut as low and chopped as finely as practicable, leaving it spread evenly as a mulch to stimulate re-growth of grass. In orchards the trees largely dictate the width and location of the mower in relation to the tractor wheels. Several distinct types of purpose-built machines are now offered. One of the most adaptable is a descendant of rear-mounted flail mowers with a Cat2 three-point linkage and right-angle countershaft drive from a sturdy gearbox via four end-drive V-belts to the high-speed horizontal flail-carrying shaft. Double-edged reversible curved flails are kept in cutting position by centrifugal force but can swing back if an immovable obstacle is encountered. Handed vanes bolted to the inner side of the hood can distribute the chopped material widely. (*Kidd Pasture Topper*).

For open-field pasture-topping simpler alternatives to the rear-mounted multiple flail type can include a side-mounted model of the vertical axis rigid bar rotary flail type equipped with two rotors and double renewable flail at each rotor end. The lower swinging flail is angled downwards so that the main rotor arm normally stays well clear of immovable obstacles. The trailing edge of the upper flail is angled upwards to provide air disturbance to assist spread of the cuttings. The drive incorporates shear-bolt and overrun protection, and a linkage break-back safety device. Road transport is catered for by a 90°



Fig. 11.14 Three-point linkage mounted 2.4 m (8 ft) offset pasture topper incorporating two horizontal steel rotors with a swinging flail angled downwards below the main cutting bar level. A 'thistle basher' blade is standard equipment. A break-back safety linkage is incorporated. Underside of deck is profiled to prevent swathing. (*Kidd Barber 24*)

pivot of the whole machine to place it directly behind the tractor in the raised position. (*Kidd Barber 24* Fig. 11.14)

Machines for secondary operations

When haymaking was more widely practised there was an almost endless variety of machines for speeding up drying. The advent of powerful tractors and high-speed mower conditioners, often linked to silage making systems, has made most of the non-power-driven types obsolete.

Rotating-head machines

This is an old type which, like other types of tedder, has been transformed by power drive and the use of high working speeds. The tines are mounted on stars which rotate about a substantially vertical axis (Figs 11.15 and 11.16). Where more than two rotors are used, flexibility is provided between the sections of frame, and castor wheels may be used to allow each section to follow ground

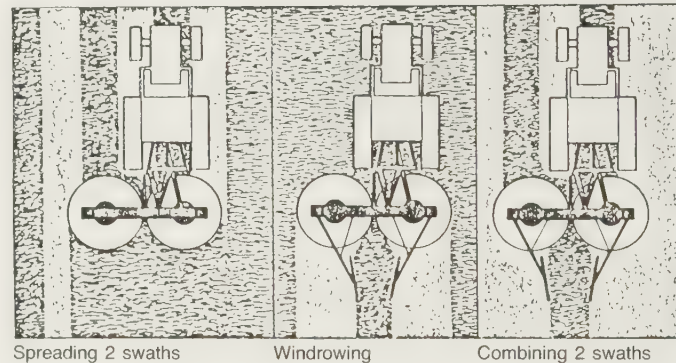
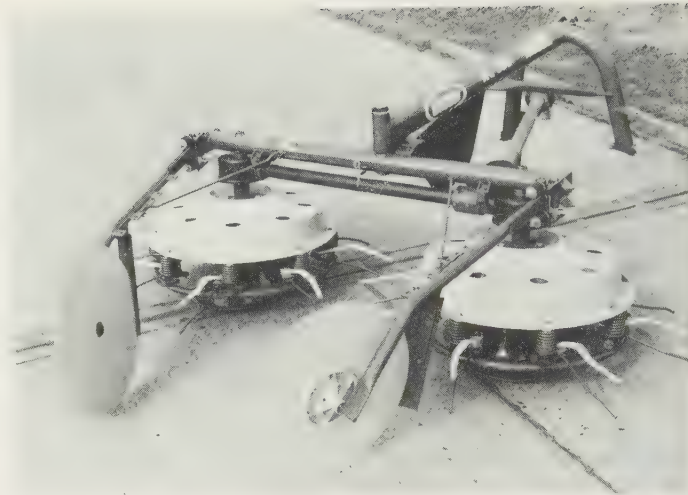


Fig. 11.15 Two-rotor mounted haymaker. The rotors have large-diameter convex adjustable skids for height control, and double tines with flexible nylon upper finger and steel lower, designed to avoid or minimise loss on breakage. Polyester rotor cover helps to avoid crop tangling; rotating flat disc polypropylene doors can be set without tools. Some setting options are illustrated in diagrams below. (*Vicon 'Speeder'*)

irregularities. Design features of importance include the ease of changing from one operation to another, and the efficiency of carrying out the main operations of tedding, swath-turning, swath-spreading and windrowing. When changing from spreading to windrowing the angle of the tines is sometimes changed by a simple adjustment that affects all of the tines on each rotor. For windrowing it is usual to provide a cage or screen that can be folded out of the way when spreading. Speed is vital; so ability to



Fig. 11.16 A four-rotor haymaker spreading four swaths.
(Watveare/Deutz-Fahr)

handle three or more swaths is an advantage for large-scale operations. On some machines this is done by two large-diameter rotors, while on others up to six smaller rotors are employed. Features of individual makes include various methods of extending tines to their working position, while ensuring that they are free to avoid damage on meeting an obstruction: e.g. extension by centrifugal force, and folding by use of a light spring. Use of steel domes acting as skids in preference to pneumatic-tyred wheels avoids punctures when working near hedges and provides good following of ground contours. Replacement of steel tines by suitably designed plastic fingers can result in less breakages and more importantly in less forage harvester troubles following tine loss.

Rotating-head types have become very widely used on account of the high potential work rate, high degree of

versatility and efficiency of carrying out the essential operations. They should preferably have only a moderate tine speed, in order to minimise crop losses from loss of leaf. Ability to rake cleanly is essential. The type of windrow generally desired is of approximately rectangular shape, and vertical screens are used to assist in achieving this shape. The trend is towards machines with two fairly large rotors that provide a horizontal sweeping action, since this causes less trouble from tine breakages and contamination of the crop by soil.

Reference

Klinner, W. E. and Hale, O. D. (1984) 'Design evaluation of crop conditioners with plastic elements'. *Journal of Agricultural Engineering Research* **30** 225–63.

Silage Making and Feeding

Making silage

Traditionally most forage was conserved in the form of hay. Following the advent of improved mechanisation and the development of more effective sealing for simple silos, the balance was eventually reversed in the UK in the mid 1970s. This upward trend for silage has continued through the following decades so that by far the majority is now conserved as silage. A notable component in this move towards silage has been the introduction of big bale silage in the late 1970s: (this is now approaching 20% of all silage made).

Silage making involves complex chemical changes. Invariably the process depends on the fermentation of sugars to produce lactic acid by naturally occurring bacteria. The absence of oxygen is essential. Problems will also occur if the concentration of sugars is too low. The usual aim is to produce a feed that is distinctly acid with a pH value of 4.2 at a dry matter content of 25%. Crops at lower dry matter contents may not have a sufficient concentration of sugar and increasingly risk the production of effluent which is a serious pollution hazard. For these reasons crops are usually 'wilted' for a period between cutting and harvest.

Basic techniques for making this type of silage are now well established and will be highlighted in this chapter.

High protein crops such as a pure stand of lucerne which is about to flower, or very young lush grass which has been heavily fertilised, are low in sugars, particularly in the autumn, and are more difficult to ensile. In these circumstances the chances of a good fermentation can be improved by using a silage additive. The range of additives which are commercially available includes inorganic acids such as sulphuric, organic acids principally formic, and mixtures of acids with formalin to reduce protein breakdown. Molasses can be used to add sugar to the crop.

Although large volumes have to be applied, low viscosity formulations improve both handling and mixing.

Whatever additive is used, thorough mixing with the crop is essential; suppliers have developed power-operated application equipment suited to handling the particular product. Some of the chemicals used are potentially dangerous and must be handled with care to avoid accidents to operators or damage to equipment.

It is easier to make good silage of crops that have been chopped or bruised. Adequate consolidation is more easily achieved and it is possible to make very good silage in horizontal silos if suitable arrangements are made to exclude air by using airtight walls and sealing the silo with polythene sheet effectively weighted down over the whole surface. When short-chopped material is ensiled, it is practicable to make use of deep silos and subsequently to use a loader and trailed forage feeder for mechanised feeding. As a general rule dry matter content of crops ensiled in horizontal silos should not exceed 35%, otherwise it is difficult to avoid waste due to overheating.

Experience has shown that self-feeding of silage can be very effective, especially for medium sized dairy herds. The essentials of a good labour-saving layout of silos, cow housing and milking parlour are now well understood and there are many variants to suit individual needs. A silo for self-feeding should be provided with rigid, airtight walls and should generally be capable of providing up to 1.8 m (6 ft) depth of settled silage. Width should generally be not less than 6 m (20 ft), and preferably more, according to the size of herd. A simple method of filling horizontal silos is to tip the crop on concrete near the silo, preferably alongside a solid wall, and to transfer it to the silo with a push-off buckrake fitted with short tines. High output tractor attachments and specialised handling vehicles are increasingly used for this work in order to match the output of forage harvesting systems with the minimum of

manoeuvres. The same basic equipment is later used to unload the silo.

Full-scale experiments have shown that typical total dry matter losses between cutting the crop and feeding it from common types of silo are approximately as follows.

	<i>Total dry matter loss (%)</i>
Unwalled clamp	30–45
Small walled horizontal silo	20–30
Large walled horizontal silo with plastic seal	15–25
Large tower silo	10–20
Big bale silage	8–30

With application of the best techniques which are now widely accepted, the level of loss should be towards the lower end of the range.

Machines for collecting green crops

The history of development of machinery for collecting green crops shows how rapidly machines can become obsolete. Green-crop loaders which delivered long crops on to the front or rear of a trailer and needed a couple of men with hand forks to build a load were quickly superseded by ‘one-man’ loaders and self-emptying trailers, and by buck-rakes; but it was not long before both of these were made obsolete by forage harvesters. One-man loader-wagons with facilities for chopping wilted windrowed crops reasonably short have some advantages. More recent developments in forage harvesters have been aimed at increasing the degree of chopping, improving reliability and utilising the increased power available from the modern range of tractors. Consequently the simplest types of flail forage harvester have largely been superseded and at the same time there has been a marked increase in the use of big bale systems considered later (p. 204–6).

Forage harvesters

Double-chop flail type

The double-chop harvester uses a flail mechanism for the cutting or picking-up operation, and usually employs an



Fig. 12.1 ‘Double chop’ (flail and flywheel chop) forage harvester shown picking up mown swath. Full electric control of spout and deflector from tractor cab is provided. Through drawbar can carry pick-up hitch for loading to trailer drawn in tandem. Harvester can also be used for direct cutting an unmown crop. (Ford New Holland)



Fig. 12.2 Side-mounted ‘crop-chop’ forage harvester picking up a wilted swath is well suited to gradient work. The 24-blade chopping cylinder, directly pto driven from a right-angle drive gearbox, mounted on the three-point linkage attachment frame, moves upwards over the shear plate, throwing the crop directly up the delivery chute. The chute folds forward for easy access to the rotor. The trailer is directly ring hitched to the tractor pick-up hook. Height of the machine pick-up is regulated by vertical adjustment of the machine’s front wheel. (Kidd Crop-Chop M)



Fig. 12.3 Flywheel type metered-chop forage harvester. Finger-tip in-cab controls provide electro-hydraulic delivery spout movements: instant reverse of feed mechanism to avoid blockage, and trailer tipping. (WestMac Taarup 106B)

auger running just behind the rotor to move the crop sideways to a flywheel type chopper mechanism, fitted with paddles and a delivery chute similar to that employed on a full-chop machine of the flywheel type. The material is not presented to the chopping mechanism with all the stalks at right-angles to the knives and shear plate; so double-chopped material is more variable in length and less suitable for mechanical feeding than that produced by a metered-chop harvester.

A typical machine with a maximum output of 15–20 tons/hour absorbs 30–40 hp (22–30 kW) at the pto when used at optimum efficiency. Specific outputs suffer if the machine is operated at a low forward speed in light crops.

Metered-chop forage harvesters

Priorities of typical users do not remain constant over decades of development and experience: users are influenced by:

Length and uniformity of chop: With improvement of handling machines a very short chop length is no longer considered ideal for grass crops. Early machines were much influenced by the need to handle forage maize.

Damage from tramp metal: The problem remains of great interest. Methods of avoidance include prevention of metal entering swath; detection and prevention of metal entering chopper; and design of blades to minimise consequences of entry.

Avoidance of time waste by blockages: Performance in difficult conditions can be transformed by a well designed mechanism for instantaneous reversal of feed flow.

Flywheel type harvesters

Modern machines are basically similar to very early types but much improved in important details. A typical machine with heavy-duty flywheel about 1.25 m diameter may be fitted with 2, 5 or 10 radial curved knives. The multi-speed feed rollers incorporate an instantaneous reverse; sharpening by an all-over rotary grinder is done in reverse drive in 3–4 min. Some designs for middle-range tractor power cater for either rear-mounted, trailed or front-mounted use on a reverse-drive-equipped tractor.

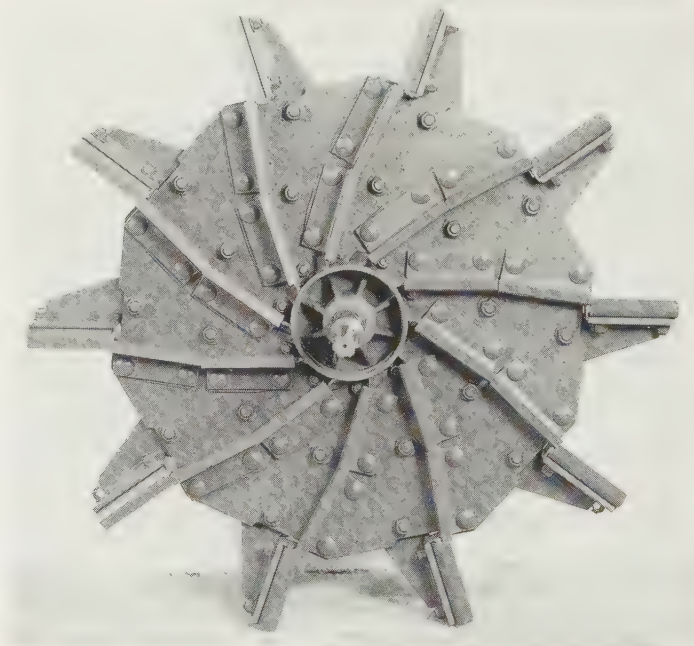


Fig. 12.4 New 30-knife flywheel in ten rows as used on Taarup 106B. Flywheel diameter is 1 m. Knives are designed to bend backwards and inwards under excessive loading. (WestMac Taarup)

As with cylinder type harvesters, there can be advantages in replacing older designs by a multi-knife system, employing knives of a trailing-edge type which can bend backwards and inwards from the shear-bar to avoid serious damage and to restrict the size of the component needing replacement (e.g. Taarup 105/6).

Cylinder type with full-width knives

Typical harvesters have cylinders of approximately equal width and diameter, ranging from 457–610 mm (18 to 24 in) (Figs 12.5 and 12.6). Cylinder speed is usually about 1000 rpm for average diameters and attainable chop length can be down to 5 mm ($\frac{3}{16}$ in). A longer chop is often adequate, and can be achieved by reducing the number of knives or by increase of feed roll speed.

One of the chief problems is the serious damage that may occur if unchoppable materials such as metal stakes, tools or machine parts are picked up with the crop. Special damage-avoidance features include an electronic metal detection system (e.g. Ford New-Holland). The detector, located in the lower front feed roll, transmits an electrical impulse to a solid-state control module, which in turn disconnects the drive to the feed rolls. The whole process from detection to preventive action is completed within 0.05 second.

The built-in sharpener on high-output machines may be power-driven, self-adjusting, and accompanied by a

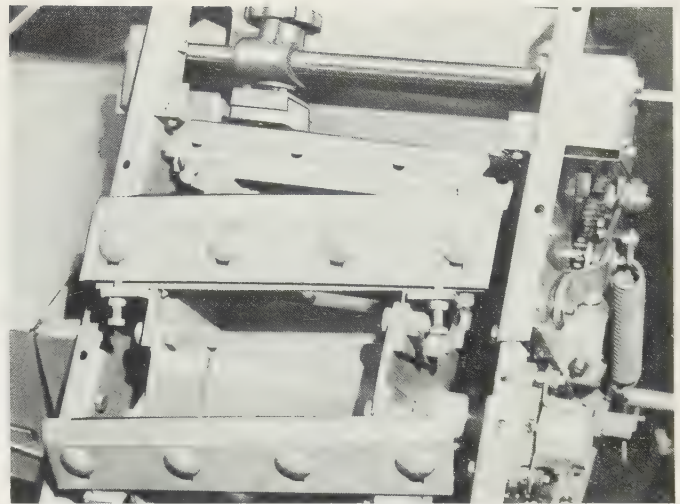


Fig. 12.6 Chopping cylinder and sharpening stone in a metered-chop forage harvester. (Claas)

cylinder reverse drive mechanism. On medium-output machines the sharpener is usually non-rotating, but may incorporate an automatic advance to control the amount of metal removed each time the sharpener handle is operated. It is advisable to sharpen knives often, without trying to remove all deep nicks.

Multiple-knife cylinder type

European designs for medium-duty machines show a trend towards a type of large-diameter cylinder with multiple knives, each only a fraction of the cylinder width (Fig. 12.7). These are designed to avoid serious damage by foreign bodies to the complete cylinder, by allowing individual knives either to bend or to be forced inwards to create a wide clearance between knife and shear-plate. A serious obstruction taken into the cylinder may cause several knives to be replaced; but if the main structure of the cylinder, shear-bar and housing remains intact, it should be possible to replace the knives and continue work within a few hours. Other changes include simplified feed and delivery systems. One simple design (Fig. 12.8) uses a very wide 'contra-rotating' cylinder in conjunction with a pair of feed rollers. Such a design is claimed to eject foreign bodies such as small rocks, and to use little energy in propulsion of the crop.

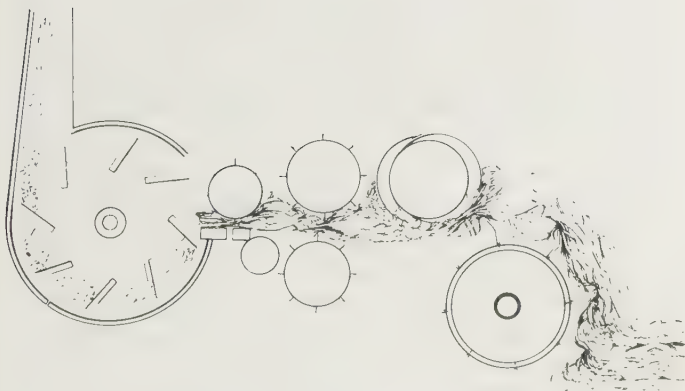


Fig. 12.5 Arrangement of pick-up, feed rollers and chopping cylinder in a metered-chop forage harvester. (Ford New Holland)

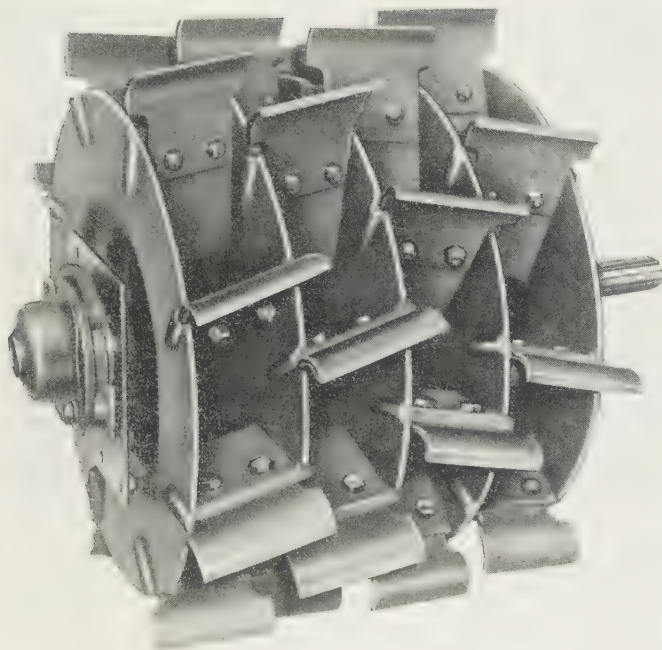


Fig. 12.7 Multi-knife cylinder with a large number of narrow blades designed to avoid major breakages if large metal object is picked up. (WestMac-Taarup)

Some of the newer designs achieve a high throughput in relation to power input, partly as a result of less chopping. The fineness and uniformity of chop are nevertheless adequate for the effective use of the improved mobile machines now available for silage removal, mixing and feeding.

With all high-output forage harvesters, effective and rapid adjustments of the discharge chute angle and of the flap are essential: electro-hydraulic systems are widely used.

Harvesting maize for silage

Most metered-chop forage harvesters can be provided with attachments for harvesting whole-crop maize for silage. The attachments usually consist of sheet-metal dividers, assisted by a pair of feed chains which grip the stalks while they are cut by a reciprocating or rotary knife, and then convey the crop, butts first, to the chopping mechanism. The two-row attachment normally provided for a medium-sized forage harvester is comparable in

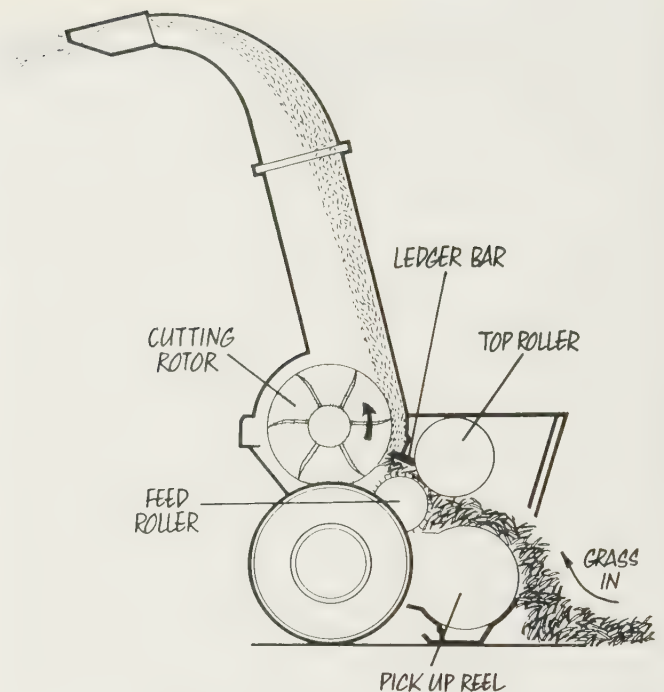


Fig. 12.8 Forage harvester design with pick-up, pair of feed rollers, and wide contra-rotating cylinder. (J.F.)

cost and complexity with a single-row complete maize harvester that is designed for this specific purpose. The mechanisms used in single-row harvesters are very varied. Some use feed chains, a power-driven knife and a chopping cylinder very similar to those employed on multi-purpose harvesters. Simple types include one with a pair of contra-rotating drums, with notched wheels to press the stalks against a single fixed knife, and chopping by a flywheel-type mechanism. A typical one-row unit working in a good crop provides a full load for tractors of up to about 50 hp (37 kW).

With modern earlier maturing varieties of maize which are harvested at higher dry matter levels, there is increasing concern to damage each kernel for effective digestion by the animal. Manufacturers are incorporating various devices to achieve this. Cylinder and flywheel choppers can be fitted with various forms of serrated or 'aggressive' concaves. With some high output self-propelled machines, close fitting contra-rotating serrated rollers are positioned immediately behind the chopping mechanism. These are swung out of action when harvesting grass.

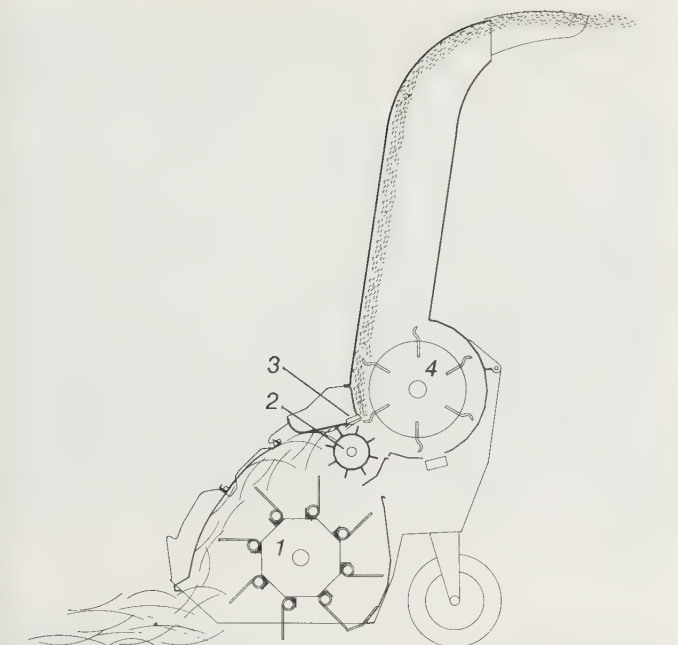


Fig. 12.9 Essentials of new Teagle 'Toucan' Forage Harvester. 1 Heavy-duty spring-tine pick-up with eight-bar rotor, the only moving part, runs at high speed and relies on centrifugal force to push swath to 2 single feed roll with deep serrated bars to grip the crop and pass it firmly to 3 shear bar made from chrome molybdenum and having a tungsten carbide hard face. The heavy-duty 4 rotor has 36 individual chrome molybdenum knives rotating in a manner already proved to be efficient for trailer loading. (*Teagle Toucan*)

Metered-chop harvester/tipping trailer combination

A combination of a simple proven metered-chop harvester mounted on a proven tipping trailer (e.g. Teagle 'Toucan') has been established as sound in principle, redesigned using a new Teagle-made harvester, and has now been found by many farmers to offer an effective low-labour system which admirably meets their silage-making needs. Work rate and chop length can satisfy a wide range of needs, and availability of the trailer on its own for a substantial part of the year can be of real value.

Systems of operating forage harvesters

The most common method of using a forage harvester to make silage involves delivering the crop into a trailer



Fig. 12.10 Teagle 'Toucan' at work. Full electric controls. When empty, trailer can easily be separated from harvester and used for normal transport duties. (*Teagle*)

towed behind the harvester, tipping the trailer on to a hard apron at the silo and then getting the material into the silo by using a buckrake. If all of these jobs are to proceed simultaneously, the minimum gang size is three men, and this size of gang is in fact well suited to a wide range of conditions. Each man drives a tractor, and two tipping trailers are needed. Silage-making by similar methods can, however, also be carried out by either one, two or four men. When one man works alone he may run directly to the silo and tip several loads without unhitching the harvester; he will then ensile these loads later. Similarly, when two men are engaged they may leave ensiling until later, or one of them may do the transporting in addition to loading or ensiling. With four men, three trailers may be used and very long hauls at high loading rates are possible.

An ADAS investigation shows that while a spot loading rate of 30 tonnes/h is common for a tractor pto-powered trailed harvester, achievement of an overall rate of 20 tonnes/h depends on such basic factors as providing a windrow containing at least 5 kg of crop per metre length, and maintaining a pick-up speed reasonably near to 7 km/h. The forward speed limit is often set by ground conditions, but is considerably influenced by operator's choice.

Self-loading forage wagons

Loader wagons, originally designed for handling hay on family farms in Central Europe, have been redesigned and strengthened for making wilted silage. A typical machine is centrally hitched behind a tractor which has its wheels set out to straddle the windrow. The machine works well behind a rotary mower-conditioner, after a suitable period of wilting. A tined pick-up delivers the crop to a chopping mechanism based on stationary knives. Early machines used an endless-chain conveyor to draw the windrow across the knives, but newer designs use rotary mechanisms to press the crop between closely spaced knife banks, capable of producing a medium or short chop of fairly consistent length, suitable for modern silage-making needs (e.g. Reco-Mengele Garant 33, Taarup 1030 etc.). In the Taarup, nominal chop length can be 20 mm or multiples obtained by simply picking out knives from a pivoting frame which provides easy access and a spring overload release in six independent banks across the full width. Nominal chop lengths of 50 or 100 mm (e.g. Mengele) are a more usual aim. Knives, individually spring-loaded, are carried in two banks, the lower of which can be swung out of action to double the chop length if required.

The very short chopping in the Taarup 1030 is effected by a feeder-cutter with spirally arranged star-shaped vanes to force the crop between the knives. Easy control of operations is provided by a cab-mounted electro-hydraulic control box, giving pick-up height adjustment, steering by swinging drawbar, activation of chain-and-slat floor conveyor and operation of tailgate. Dense loads can be formed by intermittent operation of the floor conveyor.

Equipment for filling horizontal silos

The work rate required depends on silo size and harvester outputs. Overall rate needed may range from 6 to 60 tonne/h, 12 to 20 being a more common need. High output requires high power and a short chop. The simplest satisfactory equipment is a tractor rear-mounted push-off buckrake. A front-mounted push-off buckrake makes the driver's work in some respects easier, but requirements for a satisfactory performance include large front tyres, preferably four-wheel-drive with power steering, and a large counter-balance weight at the rear. The best perfor-

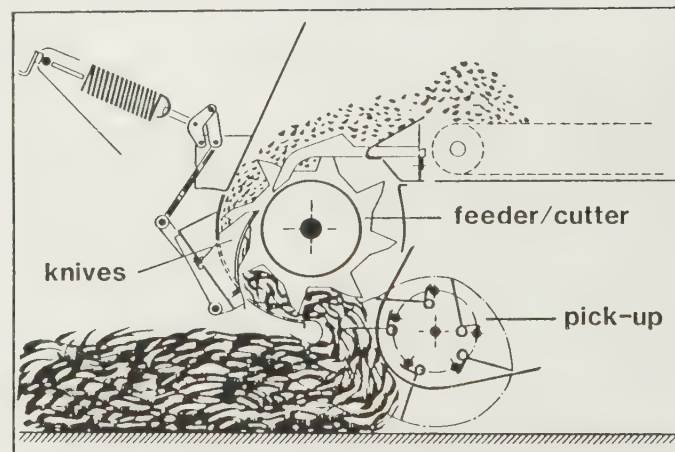
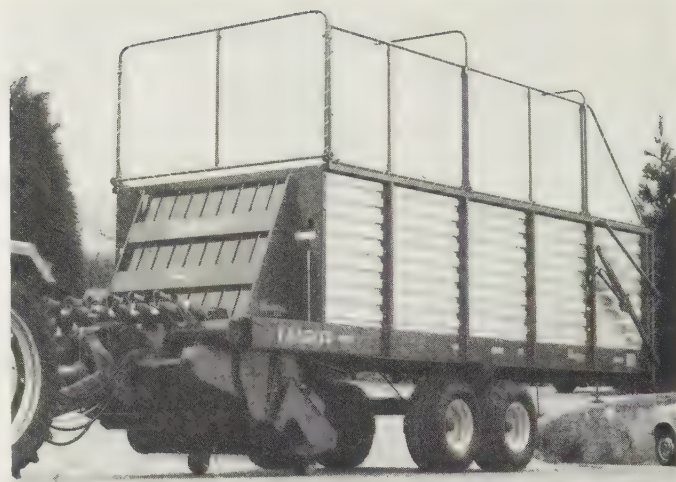
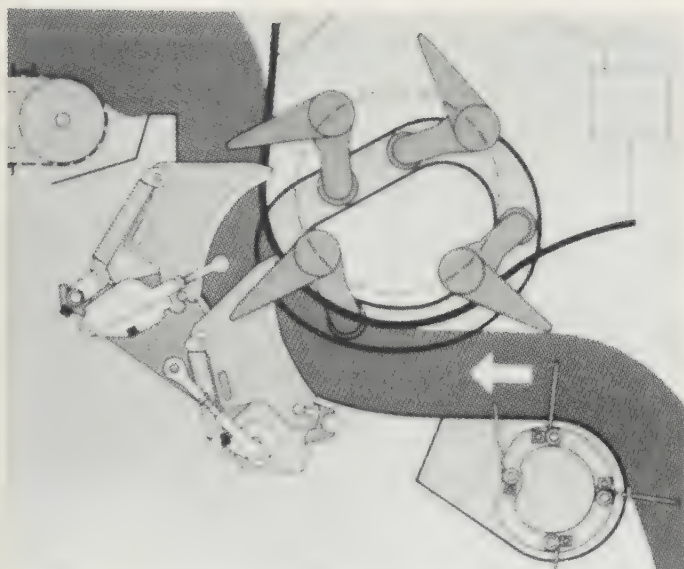
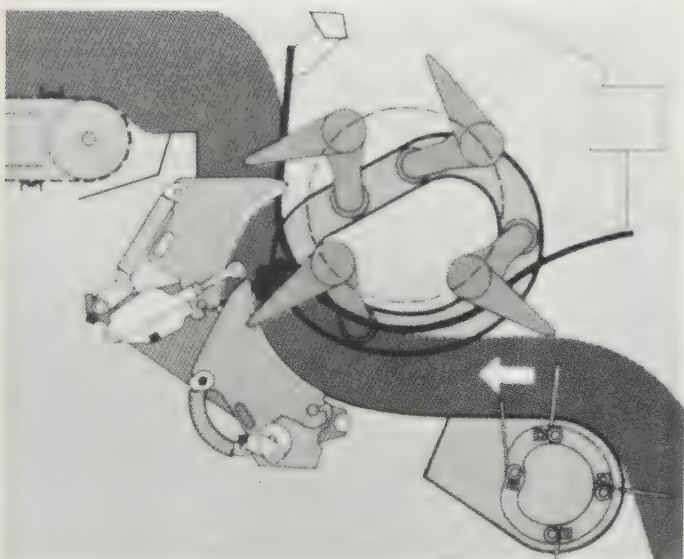


Fig. 12.11 Short-chop forage wagon. (WestMac/Taarup) Loader wagon has tandem wheels. The knives are carried in groups in a swinging frame, with spring overload release in each group. Chop length can be quickly adjusted to suit conditions by removing alternate knives; knives can be either removed or replaced without the use of hand tools. The diagram illustrates the action of the cylindrical feeder/cutter mechanism which forces the crop between the knives.

mances are achieved by high-powered four-wheel drive rough-terrain loaders with fairly large equal-size wheels, high ground clearance and preferably a telescopic boom with large-capacity push-off buckrake or tined grab. For high-speed work, the buckrake needs to be a heavy-duty



(a)



(b)

Fig. 12.12 High Capacity Swinging Packer Loader Wagons. (*Reco Mengele 'Garant 33'*)

(a) Normal Use: The cutting mechanism consists of two rows of stationary serrated curved knives carried in a frame which can be fitted with wheels to assist easy removal for spacing or sharpening. The four swinging packers sweep the windrow from the pickup and force the crop through and up to the wagon floor conveyor top left.

(b) The Trimatic safety system allows a foreign body to escape upwards and springs later return the knife to normal position.



Fig. 12.13 Rear-mounted scissor action push-off buckrake with working width 2 m.



Fig. 12.14 Articulated-steering four-wheel-drive handling vehicle with equal-size wheels has good climbing ability in soft conditions on nearly-full covered silo. Large-capacity multi-purpose grab-fork has push-off incorporated. (*JCB 'Farm Master'*)

type with slim spring-steel tines, a double-acting ram, and the back partially or completely sheeted. Some other types of rough-terrain fork trucks can be satisfactory, but many are not ideal for the work owing to clearance problems, caused partly by excessive sinkage due to the weight of attachments and counter-weight. A 60 hp vehicle is needed to attain a work rate of 40–50 tonne/h.

Experience in Britain from 1950–90 on use of tower silos for making, preserving and feeding mainly grass/clover crops showed that well planned and constructed installations for a livestock enterprise with an assured future, e.g. milk production, could be both technically and economically successful, but gradually tended to emphasise high capital costs of such systems. A fairly high level of physical depreciation of both silos and fixed machinery for filling, emptying and rationed feeding also has to be considered, together with the physical and economic difficulties of changing to improved types of equipment, or profitably disposing of the old. During the same period there were many important developments in mobile equipment and alternative storage methods for silage. In particular, the already substantial increase in use of big balers for taking big bales of silage from fields to the livestock has been accompanied by improved and labour-saving methods of using air tight plastic sheeting for long-term storage. This has naturally been accompanied by a steady increase in the importance of mobile mixer-feeders equipped with reliable electronic weighing equipment to facilitate the development of accurate 'complete diet' feed systems.

In these circumstances, details of tower silo systems are omitted from this 12th edition of *Farm Machinery*.

Unloading horizontal silos

To minimise wastage, the aim of all clamp unloading systems should be to cause minimum disturbance to the silage remaining and leave a tidy compact face. Mobile hydraulic loaders are now commonly used for this purpose. The most effective have close tine spacing and a crowding grab fitted with sharp blades on the leading edges and sides (e.g. Parmiter Shear-Grab). The remaining silage face can be left substantially undisturbed. With a specialised handling vehicle there may be no need for other transport equipment where distance is short and a suitable feed fence is arranged. For longer distances loading can

be into a wide choice of tractor-mounted or trailed silage feeders, unloader-feeders or mixer-feeders considered later.

Silage block cutters

Parmiter won a RASE Silver Medal Award for their hydraulically reciprocated tractor-mounted silage block cutter designed for unloading horizontal silos many years ago. It is significant that Parmiter's efforts in the same field of work received similar recognition in 1987, this time for a relatively simple but effective shear grab. Most of the silage stored in horizontal silos with airtight walls or linings and top seal is chopped by forage harvester and well suited to being handled in the first stage of emptying by a grab of the general type illustrated in Figs 12.15, 12.16 and 12.17. Grab capabilities appropriate tractors and handling vehicles of different sizes are approximately:

	Model	m ³	ft ³
Small tractor	SG 100	0.48	17
Medium tractor	SG 200	0.77	27
Specialist handling vehicle	SG 300	1.23	43



Fig. 12.15 Shear Grab in action clearly illustrates the basic method of use, which leaves the silage face with a smooth and temporarily almost airtight surface, preventing rapid deterioration. (Parmiter SG 300 used on JCB Farm Master)



Fig. 12.16 Tractor rear mounted Shear Grab silo unloader developed for European markets with mast, push-off attachment and closely spaced tines. (Parmiter SG 250)

The upper jaw is raised hydraulically: the lower jaw tines are driven into the clamp: the double-acting rams (two for the large sizes and one for the small) close on the material in an arc, cutting by a combination of hydraulic pressure and sharpened front and side edges of the top

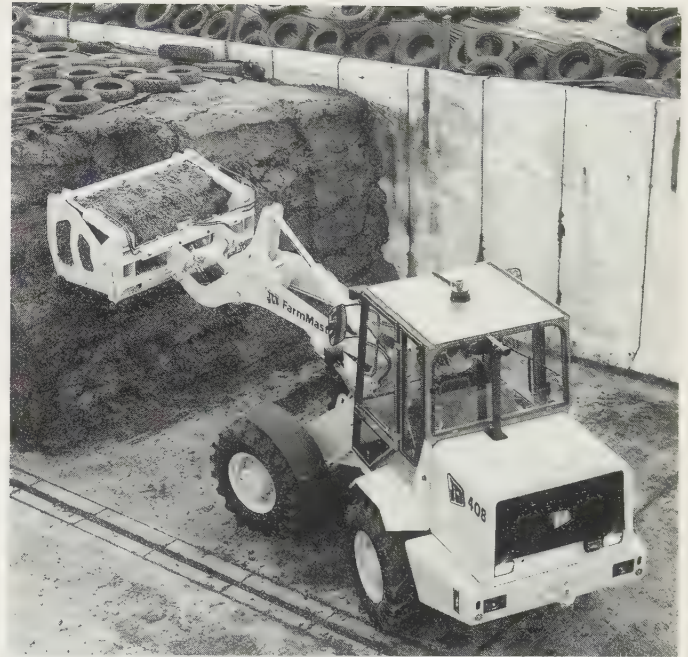


Fig. 12.17 Concrete walled horizontal silo and good top seal provides ideal working conditions for a large capacity two-ram shear grab on JCB 408 Farm Master with integral torque converter, electrically operated power shift and SYNCRO-reverse shuttle.

section. Use of a file is recommended for sharpening. The very quick cutting action can lead to a fast feeding cycle. A block shredder feeder can be attached to the SG 200 model for use of a medium powered tractor front loader to distribute the teased out silage along a feed fence.

Combined mounted unloader-feeders

Some types of silo unloaders also serve as feeders. These break up the silage as it is removed from the silo. A typical feeder consists of a rear-mounted box with a capacity of 1, 1.5 or 2 m³ with a hydraulically activated arm that moves almost vertically down the silage face and pulls the loosened material into the box. Side-emptying either to right or left is by a hydraulically driven moving floor and rotating drum. The limit of silage depth for this type is about 3 m (Fig. 12.18).



Fig. 12.18 A three-point-linkage mounted silage feeder (Audureau)

Above: Preparing for filling. Machine is lowered to ground; feed is cut by articulated spiked blade and pulled into container at end of stroke. Hydraulic controls for boom articulation and motor actions are mounted on front of machine.

Below: Feeding to floor manger via endless conveyor and hydraulically driven motor. Size illustrated has 1.4 m³ capacity; works face 2.5 to 3 m high; can be fitted with extra hydraulic drive rubber belt conveyor to deliver to higher mangers.

Mobile silage feeders and mixer-feeders

Use of a specialised silage feeding vehicle or a mixer-feeder wagon permits economic use of silage at a considerable distance from the silo. For many herds there are nutritional and economic benefits from mixing a range



Fig. 12.19 Sturdy Paddle type complete diet mixer feeder with optional electronic weighing for up to 100-cow dairy herd. The massive central paddle rotating at only 10 rpm can produce uniform mix of concentrates, etc., with fairly long silage illustrated. (Keenan Compac 70 Easifeeder)



Fig. 12.20 Largest of range of mixer-feeders designed for handling mixes of straw, silage, concentrates and brewers' grains, but equipment also available for chopping fodder roots if required. Capacity is 11 m³ (14.4 yd³). Extra-heavy-duty chassis: fodder mixed and shortened by three horizontal tined beaters in a vertical row across the front of the box. Main floor conveyor is hydraulic drive full-width rubber belt that normally moves forward towards the beaters on a bed of rollers, taking the load in a coherent block at a slow speed, infinitely variable, to the beaters. Discharge by variable speed hydraulically driven rubber belt disc to either side, and floor belt is reversible if needed. Concentrate dispenser and weighing equipment optional. Layering the feeds at loading is not unusual. Power requirement 12 kW (15 hp). Suitable for large herds and sometimes two herds. (Kidd 400 XC)

of feeds to make a complete ration based on forage. An early type of mixer-feeder-wagon or 'complete diet feeder' developed in the USA specially for feeding beef cattle incorporates three large-diameter horizontal augers running longitudinally in a V-shaped hopper. The augers, which require a considerable amount of power (e.g. 12 hp) to drive them, are designed for mixing short-chopped silages with concentrates. Delivery from the hopper is usually by means of a chain-and-slat conveyor, with a hinged extension to facilitate entering a building and then delivering well into the manger.

In the sturdy paddle type the main mixing function is carried out by a single centrally mounted horizontal shaft which carries slow-moving paddles in a U-shaped hopper. In a simple type the paddles deliver the feed direct at a high level (e.g. West Hi-Feeder). In another design the functions of mixing and delivery are isolated to improve the efficiency of both parts of the operation. When delivery is required a guillotine door is hydraulically raised, exposing the delivery auger which provides a very fast and complete discharge of the blended feed at a point easily seen by the operator near the front of the machine (e.g. Keenan Easi-feeder (Fig. 12.19)).

With the paddle type there is no positive movement of materials from end to end of the hopper during mixing. Users are recommended to stand the machine on level ground and to load concentrate liquids, e.g. molasses, first; then other concentrates; and to make a pre-mix of these before adding the roughages.

Use of the paddle type mixer with reasonably dry silage as a main ingredient results in a mixed feed that is typically light and palatable to cattle. The looseness of such mixes results in low capacity in terms of weight per unit volume. Considerable advantages of the paddle type can be low maintenance costs of the basic mixing mechanism, and fast emptying when a separate delivery mechanism is used.

This general type of feeder is used in complete diet systems where thorough mixing is necessary to avoid selection by the stock. As a general guide it is necessary to limit chop length of silage to about 25 mm, to 'tub-grind' any straw fed, and to run the machine during roughage loading. Electronic weighing equipment can be a worthwhile fitting on such mixer-wagons. The whole box can be mounted on electronic load cells in such a way that predetermined weights of the different ingredients can be loaded into the vehicle. A flashing light or

bell may be used to indicate when the pre-set weight has been reached.

One of the essentials for success in feeding by tractor-operated vehicles is a building layout and manger arrangements that permit vehicles to circulate freely without accident or waste of time.

A typical large-capacity machine with electronic weighing can be economic for dairy herds of about 150 upwards. The labour need on a well organised system of controlled diet feeding is about 1 man hour daily per 100 cows; and the feeding can be done by the milking staff. Trough space need for ad-lib feeding is about 350–400 mm per cow. A large trough is needed for once-daily feeding. Troughs should be designed with smooth internal surfaces which are easily cleaned and without corners to harbour stale feed. Careful consideration should also be given to the design of barriers to avoid damage to feeding cattle.

The large Keenan Combi-feeder 100 is designed to take full advantage of feeds such as fodder beet, which usually need a good washing and chopping before mixing with other feeds in complete diets. The dirty beet is first washed by rotation of the central paddle; soiled water is released, and the roots are given a final rinse before using a bolt-on rotary chopper (Fig. 12.21). It is claimed



Fig. 12.21 Large capacity complete diet feeder with option of built-in chopper for root crops such as fodder beet to give cleanliness and consistency suitable for mixing with other forages, straights and by-products to produce economic diets. (Keenan Combi-feeder 100)

that up to 2.5 tonnes can be washed, rinsed and chopped ready for mixing in seven minutes. Dirty water runs off to reclamation area and is later re-used for first washes. A feature of this type of feeder is ability to feed out a completed mix in only about three minutes.

Big-bale silage

The care needed for success with big-bale silage needs emphasis. It is essential that anaerobic conditions in the bales be established fairly quickly and maintained until opened for feeding. In practice, density of typical roll bales in polythene bags is about 300–350 kg/m³; this is only about half that of typical settled clamp silage, and the results of damage to polythene by pests or accidental puncturing can be disastrous. For these reasons special care should be taken to protect stored bales from wind damage and vermin such as rats.

Weight of a typical single bale is about $\frac{1}{2}$ tonne so mechanical handling is essential, but can be inexpensive with use of common types of tractor hydraulic loader. An advantage of the system for farms new to silage-making is that with baling done by contract, capital cost for a practical trial can be very low. As small quantities can be conserved without the need to open a sealed clamp, the technique is particularly useful for surplus grazing and late cuts.

There is every advantage in wilting to 30–40% dry matter when practicable. This avoids all effluent problems and reduces the number and weight of bales to be handled. In wet weather 20–25% dry matter should be aimed at. Bales of fixed-size chamber type can be used successfully, but the most convenient size for silage (about 1.2 m wide and 1.2 diameter) is small for straw. Variable-diameter machines with belts or chains and slats have the additional advantage of more uniform density and more complete unrolling for feeding.

In the early stages of development, individual bales were enclosed in polythene bags and a good deal of attention was devoted to such details as polythene formulation, bag tying, bale stacking and wind protection. Individual bagging can take a lot of time.

An increasingly popular technique is to wrap bales in a tough, stretchable cling film. As might be expected, the quality of film is critical, as is the need to ensure adequate overlap of successive wraps. Following a spate of inno-

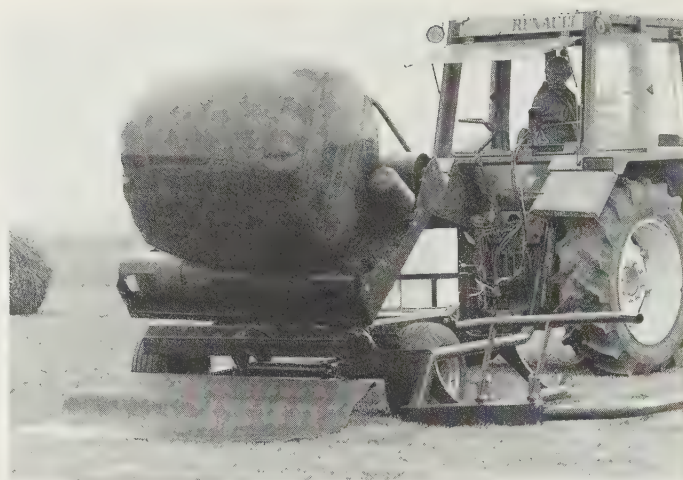


Fig. 12.22 Big silage bale pick-up wrapper dropping plastic-wrapped bale on to trailed mat to avoid piercing the wrapping film. (Volac Kverneland Silawrap 7514)

vation, two main types of bale wrapping machine are now established. A common approach is to apply film under controlled tension to the bale as it is rotated in two directions by a turntable/roller system (Fig. 12.22). Alternatives include rotating the film applicator around the bale as it is slowly turned. Attention is now being applied

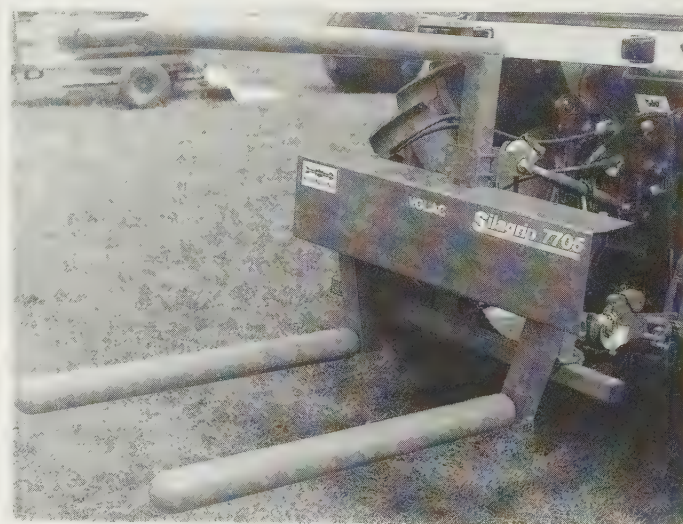


Fig. 12.23 Tractor hydraulically operated wrapped silage bale handler with freely rotating sleeves on the two bottom grip tubes. (Volac Kverneland Silagrip 7705)

to speeding up the process by attaching wrappers to the baler, doubling up wrapping with collection, and wrapping bales in a continuous tube.

Particular care is clearly needed for all subsequent handling operations to avoid damaging the film or separating the wraps. A range of smooth faced gripping devices is available for handling wrapped bales (Fig. 12.23). Easy and safe transport of plastic-wrapped bales from field to store can be carried out by a special-purpose transporter with hinged C-shaped tubular steel frames powered by the tractor's external hydraulics system (Figs 12.24 and

12.25). Similar care needs to be taken to maintain the seal when stacking wrapped bales and to avoid excessive deformation during storage. Current recommendations are to relate the dry matter content of the material to the height of stacking as follows:

DM (%)

< 25	Single layer
25–35	Two bales high
35–45	Three bales high
> 45	Four bales high

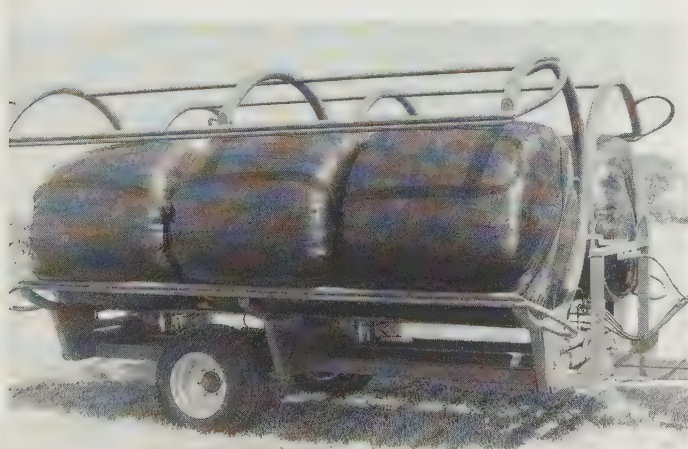
One way of overcoming difficulties in transport of wrapped bales from field to store is to transport the bales *before* plastic wrapping, using the outstandingly successful Traileyre system which was awarded the RASE Machinery Gold Medal in 1986, and is described in Chapter 13. Figures 12.26 and 12.27 illustrate the ease with which a reasonably competent tractor driver can sit in a comfortable cab to stack a load of up to eight big round bales or the now most popular sizes of big square bales on a transporter without stopping, and can travel safely at a high road speed on the highway. In the case of the round bales net wrapping by the baler can be very quick and almost invariably helps to make a first-class plastic-wrapped bale when it reaches the store. A practical alternative for a fairly large herd can be to enclose small stacks containing a week's supply in a carefully assembled double polythene sheet covering. First step is to build a neat heap on a flat, impervious base, envelop it with a sheet of 450 g material, and weight down well with sand bags. Later, a 1000 g sheet is added and this also weighted with sand bags. Medium sized rectangular bales of silage made by the balers described on page 214 will be difficult to seal individually. These are more likely to be effectively conserved in sealed packs.

A common feeding method is to drop a bale into a feeding frame, often cylindrical, from which the stock help themselves. One type of handler for use on a front loader has hydraulically operated tines which can hold a heavy bale vertically downwards to permit precise depositing (e.g. ABT).

Although machines are available to unroll bales for feeding, the most common practice has been to adapt buildings, feed barriers and feeders to allow all classes of stock to feed from bales without this complication.



(a)



(b)

Fig. 12.24 Transporter for plastic-wrapped big bales.
(a) Beginning to load. (b) Fully loaded. (Volac Bale Shifta 7726)



(a)



(b)

Fig. 12.25 Automatic silage big round bale plastic sheet wrapping using Reco Auto-Wrappa.

(a) An automatically net-wrapped bale ejected from the Reco/Gallignani 9520 baler has been drawn into the open-fronted mobile wrapping cage where it has triggered a micro-switch causing rollers in the base of the cage to rotate the bale. The wrapping reel visible inside the cage at rear left is attached to a rotor which moves round the bale in a horizontal circle, with relative floor roller and rotor speeds set to give a 50% overlap of the 500 mm wide plastic strip.

(b) When the required length of wrap has been applied, the wrap is automatically seized and cut; the wrapper arm stops at its appointed place near the front opening, and the top-hinged rear gate is partly raised ready for the bale to be gently rolled out to the rear unless the operator by over-ride control chooses a better drop point.



Fig. 12.26 Transport to store of net-wrapped or twine-tied big round silage bales is comfortable work which can be carried out without leaving the cab. (Traileyre System)

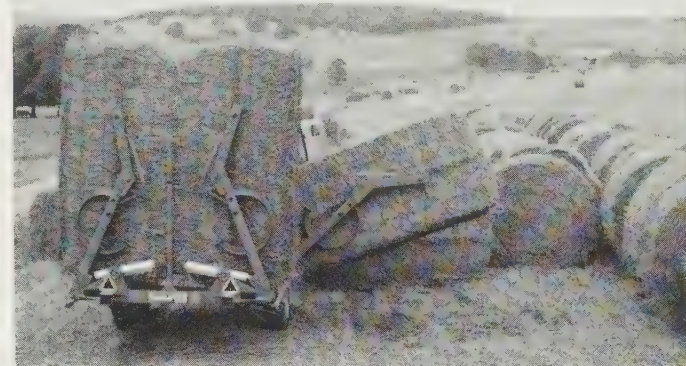


Fig. 12.27 With new (patented) two-prong spring-loaded articulated forks, eight large-medium rectangular silage bales are handled as fast and efficiently as the round ones. (Traileyre System)

References

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Haymaking, Balers and Bale Handling

Haymaking tends to be a somewhat inefficient conservation process which on average results in loss of about 30% of the nutrients contained in the crop as cut. There is therefore a need to reduce waste during the making process: not only visible waste due to leaching and shatter losses in the field, but also waste due to respirational and moulding losses before and during storage.

The effectiveness of hay as a feed depends to a considerable extent on the composition of the sward and its stage of growth, the latter factor exerting a major influence on digestibility. Hay well made from basically good raw material at the optimum stage of growth can have a feed value equal to that of the lower grades of dried grass. At the other end of the scale it may be worth less than good barley straw.

The need for speed in haymaking is paramount. The sooner respirational activity is reduced to a very low level, the lower the losses of nutrients are likely to be. Respirational activity subsides as the moisture content of the plant leaves and stems falls: provided mechanical methods used to speed drying are not severe enough to cause shattering of the leaf, the sooner hay is dried in the field to a level appropriate to the storage method used, the better. Dry spells of longer than three or four days are all too rare in late May and June and it is essential to start haymaking at the beginning of such spells.

Hay baling

Though there are many other ways of handling hay from field to store, some of which are discussed later, the most widely practised method is use of a pick-up baler of the type that makes compact, rectangular bales of a size small enough to be lifted by hand when necessary. Reasons are that baled hay is easily stacked and occupies less

space in store than long hay; and small bales form a convenient unit for stock feeding.

The need to avoid manual work in handling fodder has led to the development of other mechanised methods, notably use of 'big-balers' which make bales designed for handling by use of mechanical power: this trend is discussed separately. When using pick-up balers of conventional type, requirements as to moisture content at baling, bale density and treatment of the crop after baling vary considerably. Some farmers delay baling until the crop is thoroughly dry, while others deliberately bale rather early and leave the bales in the field to continue the drying process. Hay that is fit to stack usually has a moisture content of about 20–25%.

Damp patches in the windrows will cause trouble with mould. Hay should never be baled when there is surface moisture on it, since this is almost certain to result in a mouldy product. On the other hand, the crop should not be allowed to get over-dry, since this will result in the loss of a high proportion of the leaf through shattering, and will inevitably produce a fodder of low feed-value.

Whatever type of pick-up baler for bales of small size is used, the work goes better if the windrows have been made straight and uniform. As a general rule, windrows should not be very big: with most balers it is better to pick up a small windrow at moderate speed than to spend a lot of time on making large windrows.

Application of chemical additives

Many chemical manufacturers offer additives to assist preservation of hay by reduction of moulds and bacterial action. Results of independent trials show some improvement in quality of hay of moderate moisture content (e.g. 25–30% mc) when fairly large quantities of appropriate chemicals (e.g. propionic acid or ammonium

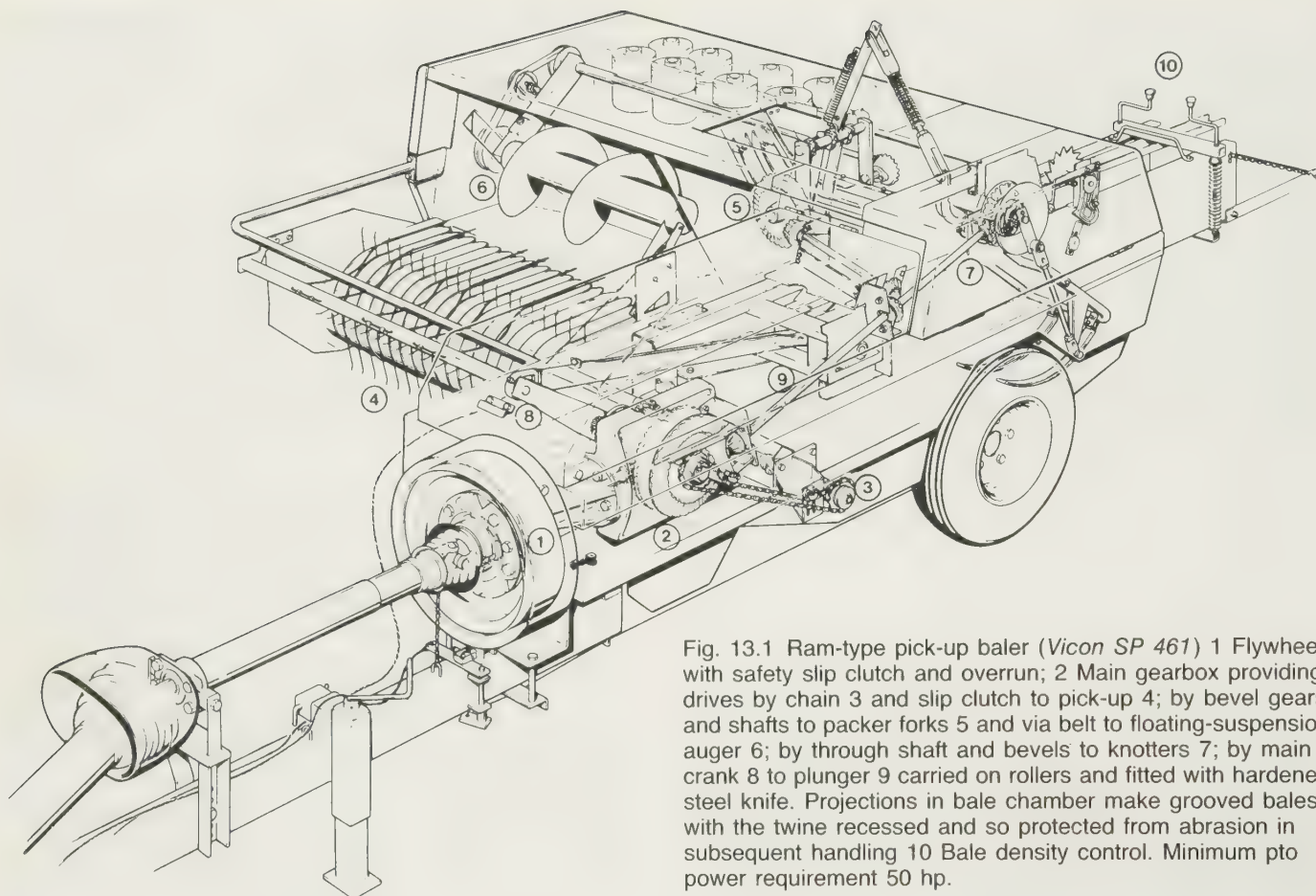


Fig. 13.1 Ram-type pick-up baler (*Viccon SP 461*) 1 Flywheel with safety slip clutch and overrun; 2 Main gearbox providing drives by chain 3 and slip clutch to pick-up 4; by bevel gears and shafts to packer forks 5 and via belt to floating-suspension auger 6; by through shaft and bevels to knotters 7; by main crank 8 to plunger 9 carried on rollers and fitted with hardened steel knife. Projections in bale chamber make grooved bales with the twine recessed and so protected from abrasion in subsequent handling 10 Bale density control. Minimum pto power requirement 50 hp.

dipropionate) are uniformly applied. With the best application methods, however, it has not been possible to find more than about 40% of the chemical used deposited on the crop. Most commercially available applicators for use on conventional pick-up balers have the spreading devices located above the baler pick-up. Both conventional spray nozzles and an electrically driven spinning disc which produces droplets of 250–300 micron size, have been tried: results of comparisons are inconclusive, and the search for improved methods continues.

Pick-up balers

Most modern pick-up balers are pto-driven, though a

separate engine is used on a few machines with a very high output. There is considerable advantage in a 'live' pto drive.

The ram type of pick-up baler

This is easily the most common, and there are many variations in the type of mechanism used for transferring the hay to the baling chamber, in the general lay-out of the machine and in the method of tying the bale. Most modern machines make a compact bale with a section usually about 450 × 350 or 400 mm (18 × 14 or 16 in), and length variable from about 0.6–1.2 m (24 to 48 in). But both larger and smaller sizes are also made. The bales

are automatically tied lengthwise with medium-weight twine of polypropylene or sisal. Wire-tying machines are sometimes used for long-distance transport of straw.

In a typical machine the plunger has a stroke of about 0.7 m (28 in) and works at about 80–90 cycles/min. There are safety devices in the main drive and in most of the main mechanisms.

The usual method of controlling bale length is by means of a metering wheel with pointed projections around its periphery, which is rotated by contact with the bale. The wheel, after a given (adjustable) movement, engages the clutch for the tying unit. After the mechanism is tripped the needles pass the twine around the completed bale, arrangements being made to ensure that this action is properly synchronised with the movement of the ram. On some machines the ram is disconnected from the crank for one revolution while the bale is being tied. The needles pass through slots in the ram, which continues



Fig. 13.2 Conventional type of small bale size pick-up baler showing simple adjustment screws for bale tension. Where bales of either hay or straw are intended for dry storage, and the crop is not as dry as desirable at baling, high bale pressure and density may lead to mould development, especially in big bales. (Massey-Ferguson)

to compress the bale until the knot is tied. On other machines the whole tying action is completed during a single revolution of the crank, and the knotting is completed at the moment when the plunger is in the forward position.

Tying the knot: Tying the knot by a typical pick-up baler takes place as follows:

- (1) While the bale is being formed, the twine disc or retainer holds the end of the twine, and the twine runs along the top of the bale, round the rear, through the eye of the needle which lies below the bale and thence via tensioning devices to the ball.
- (2) When the tying mechanism is tripped by the metering wheel, the needle comes up through the crop and places the bottom strand of twine in the twine disc alongside the top one. The twine finger moves to the rear and as the twine disc revolves, the twine finger holds both strands firmly against the knotter bills (sometimes called the bill hook).
- (3) The twine disc rotates to the next notch, and as the needle withdraws it leaves the top twine of the next bale in the next notch of the disc. The knotter bill rotates once to form a loop, and opens to grip the twine between itself and the twine disc.
- (4) The bills close on the twine; the twine is cut near the twine disc by the twine knife, and the knot is completed as the stripper sweeps the knot from the bills.

Common knotter faults are due to such causes as a bent needle; incorrect adjustment of the tension on the twine disc and the knotter bills; and blunt twine knife; or occasionally incorrect timing of the various mechanisms due to wrong assembly. With a new machine or one which is rusty, it is inadvisable to start making adjustments because of an occasional mis-tied bale. If faults persist, tension on the appropriate parts should be adjusted one at a time, so that the result can be properly checked.

Incorrect bale density is often the cause of faults which are attributed to the knotter. Excessive bale density, for example, may prevent the twine from slipping round the bale being formed due to the pressure between bales. This may result in the end of the twine being pulled out of the retainer so that a proper knot cannot be formed. At the other extreme, the twine may be so slack that it may fail to pull the knot off the knotter bills.



Fig. 13.3 Upper: European small-bale machine using 'in-line' feed system of a general type having affinity with forage wagons and high-density big-balers. Results in terms of neatness of the bales may be seen in the photograph. (WestMac/Welger Delta 2500)

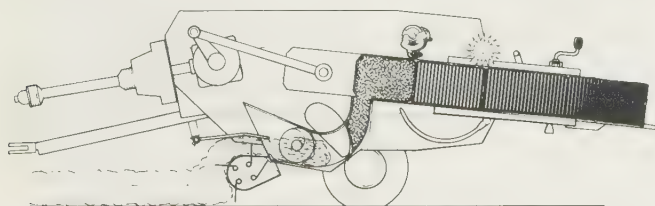


Fig. 13.3 Below: Slicing mechanisms involved in shortening and delivering the crop from window to bale chamber as shown in sectional diagram have the advantage of low power requirement. Improved manoeuvrability is an additional benefit where tractor wheels can easily straddle the windrow. (WestMac/Welger Delta 2500)

The plunger which pushes hay into the baling chamber carries a knife that slices the hay, making the layers easy to separate for feeding. Silsoe Research Institute tests of a series of medium-sized ram-type balers showed an average use of sisal twine of 1.5 kg ($3\frac{1}{4}$ lb)/ton of hay and 2 kg ($4\frac{1}{2}$ lb)/ton of straw. A typical medium-sized machine has a potential output of about six full-length bales per minute, equivalent to 6–10 tons/hour in hay or 3.5 tons/

hour in straw. When reading test reports, note should be taken of the considerable difference between 'net' or 'spot' output, and overall output. 'Spot' outputs for pick-up balers are typically about double the overall output that can be achieved in normal practice. Power required at the pto on level land is within the capacity of even a small-medium tractor.

Curved bales are a fairly common sight and they can be a nuisance not only because the twine is more liable to be pulled off during handling, but also because they are less suitable for mechanical handling methods and occupy more space than necessary in the store. The cause may simply be bad adjustment of the chute or deflector on the rear of the bale chamber. Modern balers can be operated at quite high speeds and if the bale hits the ground hard on one corner, particularly if the density is low, it is easily knocked into a curved shape.

A more common cause is incorrect adjustment of the mechanism that feeds hay or straw into the bale chamber. This can occur with both side- and top-fed ram-type balers and produces out-of-square bale ends caused by too much or too little material in one side of the bale compared with the other.

The problems of uneven feed to bale chambers are important in high-density big bales of both round and rectangular types. Electronic monitoring of bale densities is provided as standard in several newly developed big-balers. It gives a continuous flow of information on a small screen in the driver's cab which gives opportunity for required corrective actions to be taken by an alert operator.

Some machines, e.g. the Ford New Holland D1000, employ a Bale Command™ system with a parallel three-way hydraulic density control to exert a uniform pressure on both sides and the top of the bale chamber. A micro-processor measures through load cells the forces exerted on the plunger, and the bale density selected by the operator is automatically calculated and reflected in the three-way pressure on the bale transmitted by a single-acting hydraulic cylinder.

Control of bale density

Whatever type of baler is used, control of density is an important operational necessity. In the usual type of ram baler the hay charge is compressed until the force exerted on the partly formed bale is sufficient to move it along

the bale chamber. Resistance to movement is increased by squeezing together the sides of the bale chamber by means of the tension controls provided for the purpose. In haymaking, the density of the bales formed is a function of the type of material and its moisture content; unfortunately, there is always a tendency for the dampest hay to be baled tightest — i.e. the reverse of what is desired. The increased density with increasing moisture content is usually appreciably greater than that directly due to the additional water, partly because the friction between damp hay and the sides of the bale chamber is much greater. It is, therefore, necessary for the operator to make frequent checks and adjustments as the work progresses.

On the return stroke of the ram, the compressed hay is held by a variable number of fixed wedges, and sometimes by spring-loaded dogs that project into the bale chamber. When damp crops are being baled and the density is too high, wedges must be removed in pairs in order to reduce bale density, beginning with the rearmost ones.

The problems of density control are naturally of highest importance in the big rectangular balers where it is economic to design for and provide full automation with only a little steering effort by the driver involved in addition. Fortunately, where the slicing during transfer from pick-up to bale chamber is thoroughly done even very dense bales of the forage normally conserved for stock feed usually fall apart fairly easily when the twine is removed. Ability to maintain a uniformly high density depends on a suitable design of the knotters and complete tying system. The New Holland patent system combines fast movement of needles and knotters with a slow movement of the plunger, and tying of the knots is completed with the bale compressed and having 'no chance to expand'.

Collecting the bales

Whether it is better to cart the bales immediately, or to leave them in the field to dry out, depends on the condition of the hay when baled, as well as on weather conditions. If the hay is baled in perfect condition it is foolish to leave it out in the field to get bleached on the outside, to get wet if it rains and to require moving every few days to avoid mould at the bottom or spoiling the grass on which the bale stands. On the other hand, there is no doubt that in average weather appreciable drying of the

hay takes place if damp baled hay is left out in the field. Both rolled bales lying as released and ram-type bales stood on end are resistant to damage by showers, though they do suffer appreciably in continuous rain. When ram-type bales are stood on end, the end formed first should always be put at the top.

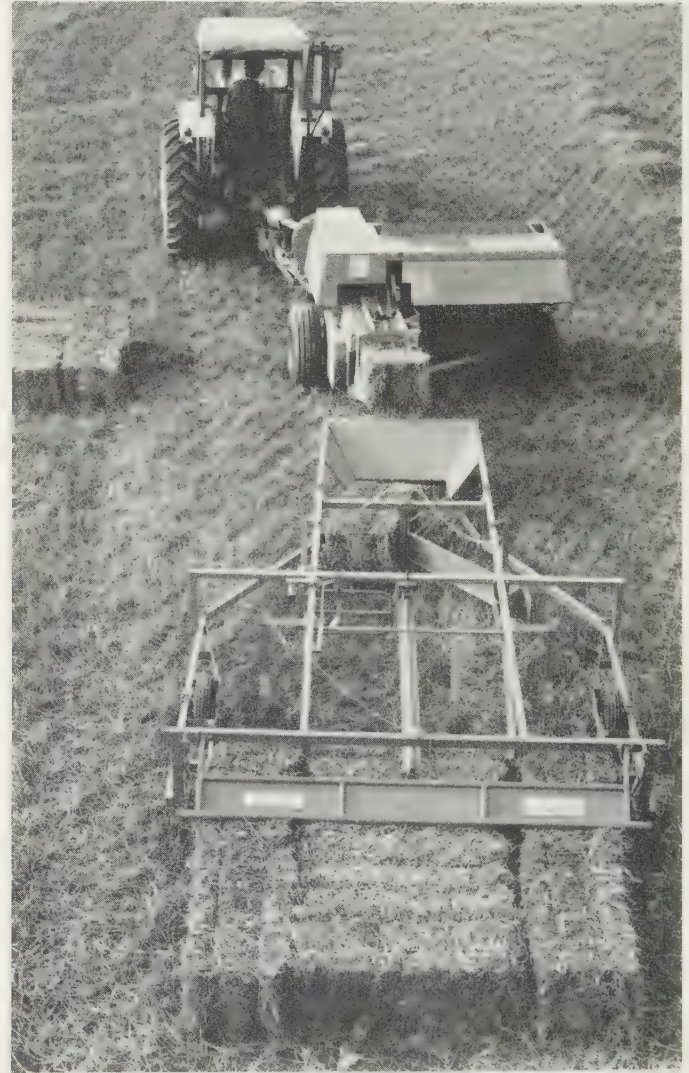


Fig. 13.4 Automatic flat-8 bale accumulator which produces a fully bonded handling unit if even-numbered layers of eight are stacked at right-angles to odd-numbered ('Bondamatic'). A similar flat-8 accumulator which keeps all bales parallel to the direction of travel may be chosen by users with stony soil surfaces. (Browns)

Bale sledges

Many types of bale sledge may be used to facilitate subsequent bale collection. A simple type collects a number of bales which are carried along in random arrangement on steel strips, until a gate at the rear is opened to release the batch in a windrow. Subsequently, the bales may be loaded singly, or, more usually, stacked into tidy groups by hand, to prepare for use of a hydraulic loader.

Most modern sledges incorporate automatic guides which assemble the bales in 'flat-8s', ready for handling from above by a fork-type loader. The sledge is towed behind the baler and incorporates an automatic release which opens a rear door when the last bale is in position. Most sledges group the bales in four rows with their length parallel to the direction of travel; in another system each bale is turned through 90° to form two rows, with the long sides at right angles to the direction of travel, e.g. Brown's 'Bondamatic' (Fig. 13.4). If these are stacked

with alternate layers at right angles to one another, a fully bonded stack results.

A disadvantage of bale sledges is that in adverse conditions the bales may become misshapen, or a string may be broken by contact with hard, stony soil. This is more likely to cause trouble with bales arranged transversely to the direction of travel, where the twine is more vulnerable.

Tined loaders

Mention has already been made of the fork type of loader which handles a 'flat-8' or 'flat-10' group of bales. This type of loader can be very effective when used with a suitable trailer. It is best to use a trailer with a strong inclined ladder at one end, usually the front, and to stack close up to this. A bar on one side of the loader can be used by a good tractor driver to squeeze adjacent groups of bales together. The layers are then automatically bonded, and large, stable loads can be quickly built.

When preparing stacks for transport by side-grip or transfer-weight carriers, bonding may be provided by stacking alternate layers with the long sides at right angles to one another.



Fig. 13.5 Hydraulically operated bale fork on four-wheel-drive tractor showing high load height capability coupled with adequate reach. (*Farmhand TT Agro*)



Fig. 13.6 Rough-terrain fork-lift with Triplex mast and 'flat-8' grab attachment loading road transport vehicle. (*Sanderson*)

Side-gripping loaders and carriers

These may operate either by means of a mechanical linkage which grips with a pressure proportional to the weight lifted, or, more usually, by means of one or more hydraulic cylinders. The main grip is usually provided by arms which squeeze the bottom row of bales, but side and rear supports are also needed for the rest of the heap. For trailer-loading, groups of eight bales are usually handled arranged four bales high with adjacent pairs at right-angles; more powerful hydraulic gripping devices are available for carrying up to 40 bales at front and rear of the tractor. When trailers are being loaded, it is worthwhile to seek means of eliminating the man on the load. This may be achieved either by 'tumble-loading', using a self-unloading or tipping trailer with high sides, or by using a trailer with a large platform and three fixed sides, the fourth side being roped after loading if necessary.

Squeeze-type loaders should have slim, smooth sides, and a positive control of position, in order to allow groups of bales to be loaded without large gaps between adjacent groups. Even with a good loader and good operation, however, it is difficult to unload trailers with this type of mechanism after the load has been disturbed during transport.

Flat-8 groups can be subsequently arranged into groups of 32 or 40 by using a suitable squeeze-type loader/carrier to lift and arrange four or five layers one above the other. The group may then be carried by the same equipment, which needs additional support at the centre of the base to prevent buckling of the bottom layer. Flat-10 groups can be assembled by the tined loader into cross-tied groups of up to 100 and transported on a specially designed two-wheeled carrier or rough-terrain fork truck.

Transfer-weight bale transporters

A typical transporter is capable of carrying stacks of 48 hay or 56 straw bales in flat 8s, or 50 hay/60 straw in flat 10s. The transporter, with clamp arms open, is reversed up to the group: the hydraulically operated clamp arms are closed to grip the bales; the load is then lifted and pivoted round the axle, until it is moved through approximately 90 degrees to rest securely on the transporter's drawbar (Fig. 13.7). With this equipment a small tractor can transport loads very fast and safely, without the tractor driver needing to leave his seat. The loads can be

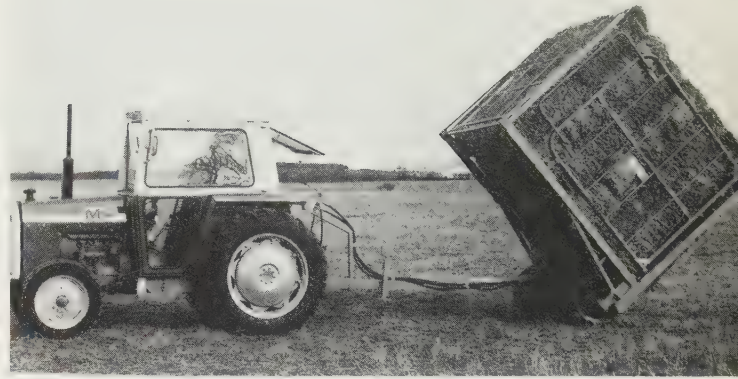


Fig. 13.7 Wheeled carrier shown with load of 48 bales being rotated round the axle to transfer weight on to the tractor drawbar. (*Ritchie*)

set down tidily near the stacking point, and stacked as a group if suitable handling equipment is available.

Stacking

There can be no doubt that the best place to stack baled hay is in a barn, and that the earlier fit hay is there, the better. A great deal of baled hay is spoiled by bad stacking; even if great care is taken with the stacking, the bales often move so much on settling, that what appeared to be a good stack becomes an untidy heap which is easily damaged by rain. With string-tied bales there is usually no need to make any special provision for ventilation, provided that the sides of the barn are open. If the hay is not really dry it is advisable to put a good layer of straw on top.

The most efficient use of covered space can only be achieved by hand stacking, and this is hard work even when an elevator is used to do most of the lifting. An extension that delivers bales nearer to the centre of the barn is often worthwhile. For some situations it is best to use a light elevator-conveyor which will lift bales 12 m (40 ft) and convey them horizontally up to 38 m (125 ft). Deflectors may be set to unload them at the required point, and in some situations it may be worthwhile to consider 'tumble-stacking'. Experience shows that with

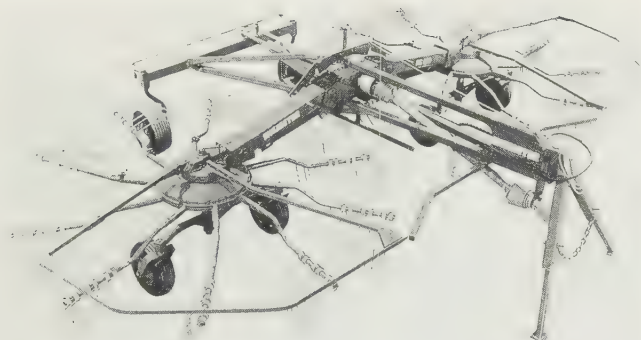


Fig. 13.8 High-performance type of rotary rake suitable for fast work on preparing straw windrows before use of big-balers. Features include automatic rear-wheel steering for short turns and easy hydraulic folding to narrow road transport width. (Niemeyer RS 620)

bales about 0.6 m (2 ft) long, tumble-stacking with such equipment can be satisfactory in barns up to 9 m (30 ft) wide. The sides must, of course, provide some support, but in any case some form of cladding may be desirable to provide weather protection. Storage capacity is not reduced by more than about 10–15% even with rough stacking. Where care is taken, records from an experimental husbandry farm show that as little as 5% of storage space may be lost.

Big balers

Developments in handling methods inevitably lead to systems that do not require manual work. For this reason, bales of a size suited to man-handling seem certain in the long run to disappear from progressive farms where high wages are earned. With most handling problems flow systems provide the best solutions because of suitability for application of automatic control; however, hay and straw are difficult to handle by flow systems unless the nature of the material is changed by an expensive operation such as cubing. It therefore seems likely that the trend towards use of big bales will develop, as good subsequent treatment and handling systems become established. The main types of big baler are the roll type and higher-density rectangular big-balers.



Fig. 13.9 In-line big baler delivering second bale centrally to Browns Tipper accumulator, which later moves it left to make way for third. Bale size is 0.8 by 0.8 m section and up to 2.5 m long. (Massey-Ferguson MF-5)



Fig. 13.10 Browns Super Buzzard Big-bale Grab can handle three bales from MF-5, Vicon 800 and Fiat Agri Hesston 4700, and four from New Holland D1000 Big Balers. It is seen on Ford Industrial 655 loader for two-bales-high loading on a high-bed trailer. (Browns Leighton Buzzard)

High-density big rectangular balers

Big rectangular bales of higher density than those produced by rectangular balers of conventional type, are made by machines with compressing and tying mechanisms specially designed for the purpose.



Fig. 13.11 The D1000 Big Baler with advanced Bale Command™ system is able to maintain a high and uniform bale density suitable for silage making with air-tight clamp conservation. The 0.60 by 0.90 m section bales can usefully be made 1.25 to about 1.5 m long for silage and 2.5 m for straw. (Ford New Holland D1000)

An early leader in this field was the Hesston 4800, which has been widely and successfully used by specialist contractors for large-scale straw baling. Purposes have included long distance road transport and off-farm sales for manufacturing. A factor limiting expansion of use for more common farming needs was the very heavy weight of the machine itself and the 1.2 m by 1.3 m cross section size of the bales. Introduction of the more recently designed model 4700 with section of 0.8 m by 0.85 m was accompanied by advanced designs of 'medium-size' big balers from both American and European manufacturers, a few of which are illustrated here. An outstanding example is the Ford New Holland D1000 (Fig. 13.11). Its bale dimensions of 0.9 m (3 ft) wide, 0.6 m (2 ft) high, and length 1.2 m (4 ft) to (max) 2.5 m (8 ft 2 in) long can be adapted to all normal European farming needs: the design of the vital crop feed and baling mechanisms is based on wide experience, and full use is made of electronic performance monitors to provide automatic control of the varied bale densities that can be selected by the operator to cover the differing needs of straw, hay and silage.

The Vicon Compact 800 medium sized square baling systems follows the Company's several years of experience with the HP1600 which uses four galvanised steel wires for tying. The bale size chosen for the 800 and the tying system are in line with other current developments, viz.



Fig. 13.12 Medium sized square baling system producing big bales 0.8 m square and up to 2.4 m long. The three-bale accumulator is shown in the tipped position and about to release the pack. It is powered by the tractor hydraulics and uses three hydraulic rams, one to position the bales and two to provide the front lift for rapid discharge. The rams are electronically controlled and operation by press button is fully automatic. An indicator screen in the cab displays operating sequence. (Vicon Compact 800 and Browns Big Bale 'Tipper')

0.8 m square section, length up to 2.4 m and four twine knotters (Fig. 13.12). As with the other balers in this size group a three-bale accumulator and a specialised group handling bale fork grab can make straw bale carting a very fast operation. The fairly high capital cost of high-density rectangular big balers makes it highly desirable to work them at a level approaching their seasonal capacity. A great advantage of the modern high-bale-density types is that their multi-use capability makes it much easier for a contractor or large-scale farmer to use the machine profitably for both wilted silage and straw.

Roll-type big balers

Early roll-type big balers developed in the USA produced shower-proof cylinders approximately 1.8 m (6 ft) in diameter and 1.5 m (5 ft) wide. European experience of drying, handling and transport soon led to the addition of machines with smaller bale chambers, typically about 1.5 m diameter and 1.25 m wide.

The principle of operation of an early Vermeer type is illustrated in Fig. 13.14. A pick-up reel feeds the windrow between a steel roller and an endless platform belt to a point where the crop is peeled off by the upper belts, which are about 100 mm (4 in) wide and spaced. These

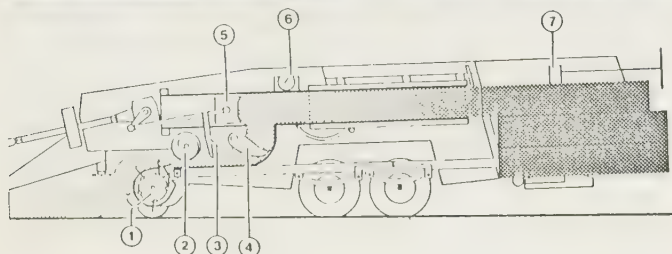


Fig. 13.13 Rectangular big-baler which makes bales 0.4 m deep, 1.2 m wide and 1.5 to 2.5 m long. Tying is by 5 knotters using plastic twine. The machine incorporates a bale accumulator which can be set to drop bales singly but more usually produces packs of two or three as shown. Diagram shows general arrangement and material flow: 1 Pick-up, 2 Feed auger, 3 Feed tines, 4 Packer, 5 Plunger, 6 Knotters, 7 Accumulator. (WestMac/Welger Delta 5000)

belts are moving in the opposite direction and start to form the roll. As the bale becomes larger, the rear main frame moves back to accommodate it, and more belt is released by the automatic bale tensioner, consisting of two idler rollers carried between a pair of pivoting arms. Springs on the arms increase bale tension as the arms rise. At maximum diameter the springs are fully extended. On some machines control of bale tension is then taken over by a hydraulic cylinder that regulates the pressure exerted on its bale by the rear gate. Twine is passed round the bale, and the rear cage moves right up to release it.

Many other types of big round balers have been developed, and many Vermeer principle machines greatly improved. Big round balers as a whole may be broadly grouped into those capable of producing a range of bale sizes (diameters) by simple adjustment, and fixed chamber-size machines where diameter is not variable. European

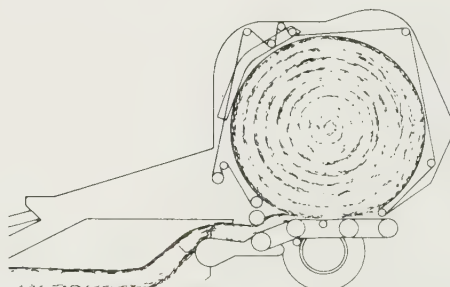
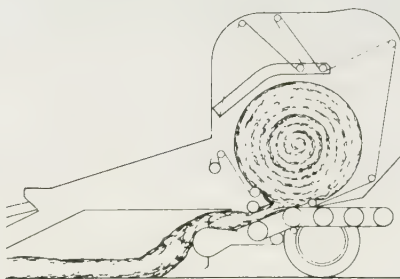
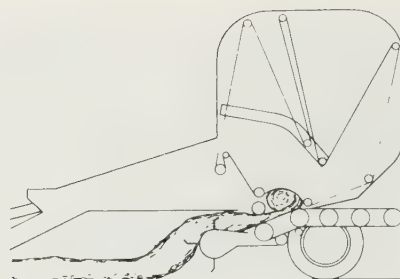


Fig. 13.14 Big roll baler: stages in bale formation. (Vermeer type)

Above: beginning of bale formation between belts moving in opposite directions.

Centre: as size increases, arm at each side moves up against increasing tension of springs.

Below: in final stages, density is partly controlled by pressure on rear door.

development of fixed chamber-size machines has been influenced by the wish to bale hay in a Continental climate and to facilitate further drying by producing bales with a soft centre. The Welger system has been prominent in these developments.

'Second generation' machines of the variable diameter type are typified by the Deere 545 and 550 which employ purpose-designed bale-forming belts with a textured sur-



Fig. 13.15 Second generation machine of variable diameter rough-surface endless belts type can produce uniformly dense hay or higher-dry-matter silage bales at high speed with electronic in-cab control of all operations including net wrapping. Illustration shows part of range of bale diameters with net wrap. Width is 1220 mm (4 ft). (John Deere 545)

face pattern on the crop-contact side to improve traction. Chosen density is pre-set by a knob on the machine which regulates the hydraulic pressure; diameter is also pre-set by a mechanical stop which limits movement of the tension arms. An electronic console in the tractor cab has needles on two gauges which continuously show up any deficiency in the amount of crop being fed to each side of the bale. Coloured lights signal stages in the bale formation and when twine wrapping has begun. After bale ejection, the driver initiates door closing and a green light shows that the machine is ready to start on the next bale.

The principle of bale formation in a machine having a main apron of chains and steel slats (e.g. Ford New Holland 835 and 865) is similar (Fig. 13.16). Crop material from the pick-up is fed under a windguard to a positive-action floor roll, which moves the windrow up to the apron chain (A). There the crop is curled upwards and immediately starts to make the bale. The chain keeps a continuous grip, and bale size is soon as shown in (B). The chain tension arms pivot to accommodate expansion of the bale in the chamber, while maintaining the uniform density chosen. When the predetermined bale diameter is reached the bale can be automatically net-wrapped and ejected.

Fixed chamber-size machines with chain-driven steel rollers are typified by the Claas Rollant and Welger RP12. A disadvantage of any fixed chamber-size is that the size

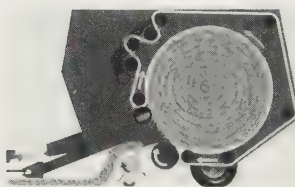
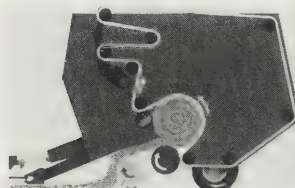
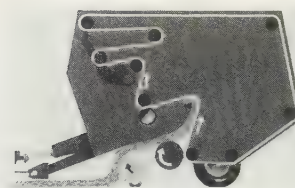


Fig. 13.16 Hard-core bale formation by chain and slat mechanism in conjunction with positive action floor roller (Ford New Holland)

most suitable for silage tends to be rather small for straw. Effectiveness of roller grip on straw is not always adequate and special paints may need renewal on smooth roller surfaces. Claas uses dimpled steel; on large Welger models sets of fairly short endless belts are used instead

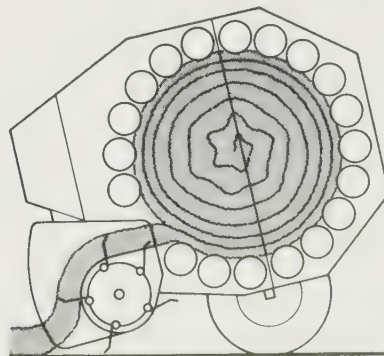


Fig. 13.17 Fixed chamber-size roll baler with chain-driven rollers provides basic conditions for formation of soft-centre bales. (Welger)



Fig. 13.18 The Rollant 46 and 66 round balers can produce roll bales with a uniform diameter of 1.2 m (4 ft) at a chosen uniform density suited to either straw, hay or wilted silage crops. A very high proportion of users buy the machine fitted with the 'Rollatex' automatic net-wrap system which not only helps to maintain shape during handling but also results in high baler outputs. (Claas UK Ltd.)



Fig. 13.19 This fixed-chamber-size machine produces bales of 1.2×1.2 m (4×4 ft). As with multi-purpose machines of similar type, net wrapping has the worthwhile advantages of tidy bales and a considerable saving of time compared with use of twine. It can maintain a consistent bale density over a range suited to straw, hay and wilted silage. (Watveare/Deutz-Fahr)

of rollers. A fixed chamber-size type of attractively simple design (e.g. Krone) employs a pair of sturdy endless chains running in channels and connected by steel rods. A range of sizes meets most needs. A simple net-wrapping system is offered.

The enclosed chamber avoids any loss of brittle material, and as more crop is fed in, bale density steadily increases. Where a net wrapping facility is fitted and roll of net is located just above the pick-up, and is fed into the bale chamber as soon as no more crop is picked up. The net wrapping control allows for settings which provide 1.5 to 4 windings before the amount selected is automatically cut off. Compared with single twine application, records show that time taken for the net wrapping job is reduced by up to 60%.

Bale wrapping with net or plastic sheet

Automatic wrapping may be by a specially developed netting or plastic sheet. A net system for fixed-chamber roller system machines (e.g. Claas Rollatex) uses rolls 3000 m long, sufficient for about a day's work. A control light on the front of the baler shows when the selected pressure on the bale is reached; the operator then stops and initiates wrapping by an electro-hydraulic system.

The net is fed in between two rollers until about $1\frac{3}{4}$ turns have been applied. A good overlap is needed to enable the net fibres to interlock sufficiently to hold. A magnetic switch activates a knife across the full width and the bale is ready for ejection about 15 seconds after initiation.



Fig. 13.20 A two-wheeled bale carrier with the long bale forks hinge-connected to cross member near front of carrier. Bales are loaded singly by sliding forks along the ground; a single acting hydraulic ram raises them for transport. Four bales can be bagged as a unit for ammonia treatment. (HFI Agriculture)

Total wrapping and delivery time are claimed to be half that for automatic twine tying; but capital and net costs are higher. Users find that net wrapping can bring the additional advantages of tidy bales with reduced crop losses, better weather protection and safer handling.

Handling big round bales

For short hauls, forks or hydraulic grippers are available for use on front-loaders and rear three-point linkage, or on rough-terrain fork-trucks. For longer hauls special-purpose wheeled vehicles of various kinds can pick up, carry and unload 5–20 or more bales.

Spikes for handling round bales by hydraulic lifts range from a single cylindrical pointed rod, on which the bale can rotate, to a group of straight spikes often of T-section, and sometimes with a hydraulically operated push-off plate to release the bale easily when setting it down. Some spikes are curved in the form of a three-pronged claw and only release when opened by hydraulic power.

Hydraulically operated spikes are used from mountings on trailers for lifting and carrying a number of bales on short- or long-distance road transport.

The Traileyre big bale handling system was invented and developed by Geoff Eyre in the mid-1980s for collecting the silage roll bales from his own slightly hilly fields and transporting them to the yard for wrapping and feeding. An experimental model attached to the flat floor of a conventional two-wheeled trailer soon proved the principle of using a line of independent hydraulically operated hinged arms, each carrying a proven silage fork, facing forwards, which could be driven into one end of a bale, raised without stopping, swung over the vehicle, and lowered with the fork holding the bale in place. By 1985 purpose-designed and constructed four-arm and six-arm vehicles were in use, and one of the latter early models with an extra bale on the rear is shown in Fig. 13.21. The RASE awarded to Geoff Eyre the Society's Machinery Gold Medal in 1986. Big baler use in rectangular big bales of straw was tackled next, and progress



Fig. 13.21 Self-loading bale trailer carrying seven silage bales; six bales are picked up separately at the sides of the vehicle by long spikes carried on hydraulically operated pivoting arms, as

the trailer moves forward. Each bale partially rotates on the arm as it is raised on to the trailer. The seventh bale shown is picked up by backing. (*Traileyre System*)



Fig. 13.22 Traileyre System for big rectangular straw bales (Hesston 4800). Equally successful with high-density silage bales produced by medium size big balers. Traileyre handling ability also includes net-wrapped and string tied round and rectangular bales.

was rapidly made here also, using pairs of linked forks on each arm which, by spring action, are pulled together during the lift, thereby preventing pulling the spikes through the edges of the bales (Fig. 13.22).

The high standards of engineering design in the Traileyre equipment are reflected in the RASE's Technology Award to the Company in 1987.

The bale transporting vehicles and the system of use recommended are among the safest available for wilted silage harvesting on steep land. Hydraulic brakes to normal agricultural tractor road use standards are fitted, and users should always ensure that they are properly connected before work begins.

A few users with a high-speed MB-Trac or Unimog tractor were able to transport bales for very long distances from fields where they bought the standing crops, and later baled and carted them home. The JCB FASTRACS (HMV) should interest many big bale users.

Stacking the bales where they will not spoil, but are handy for where they are to be individually used on a regular basis, needs careful planning.



Fig. 13.23 Only a few telescopic boom handling vehicles are capable of good work on the top layer of tall stacks of the biggest rectangular big bales, for example, Hesston 4800 size. The triple extension model seen here has no great difficulty on reasonably level and firm land, but the general demand from farmers who want to use the bales themselves is for one of the intermediate sizes. (*Sanderson Teleporter 2 Model 11-30*)

Handling chopped hay

Though pick-up balers are at present the accepted equipment for packaging hay, there are other handling methods which may be used in countries where field drying is easier than in Britain. Pick-up forage wagons with chopping knives are widely used in some countries of Continental Europe. Hay may also be handled in chopped form, using a forage harvester to pick up the crop from the windrow and deliver it to a self-unloading forage box. At the buildings, the hay is blown or mechanically conveyed into a bay or a special container for drying. Moisture content for safe storage should be not over 15%, and in Britain barn-drying is essential for success. Drying systems are discussed in Chapter 18. The equipment for collecting, transporting and feeding chopped hay can be the same as that for 'haylage' or for wilted silage, and is discussed in Chapter 12. The chopped hay is suitable for

either mechanical feeding with augers or other conveyors, or easy-feeding by fork to cattle housed alongside. Length of chop can be about 50–150 mm (2–6 in) for hand feeding or shorter where a mechanised feeding system is adopted.

Hay wafering

A method of hay handling developed in the USA involves picking up the crop from the windrow, chopping it and

then subjecting it to very high pressure in dies designed to produce large cubes or 'wafers'. The hay wafering machines at present available in the USA require the crop to be dried down to about 15% moisture content, and absorb a considerable amount of power. Trials with similar machines in Britain showed that it is very difficult to make the wafers reasonably stable, especially in grassy crops. They tend to break up on handling. A machine which requires the crop to be dried to a low level in the windrow starts with a serious disadvantage.

Combine Harvesters

The review of combine harvester developments in this chapter is made on the assumption that most readers are aware of the basic features of a self-propelled harvester outlined in or near Fig. 14.4, and that attention is focussed mainly on new developments aimed at improving efficiency in respect of items such as reduced grain losses; higher work rates resulting in keeping control of labour costs; and provision of a working environment that is safe, temperature- and dust-controlled, and in short providing a working place suited to making good use of a steadily increasing array of control instruments over a long working day. Some of the most important developments are the automatic adjustments made as a result of information from electronic sensors conveyed to a microprocessor and immediately compared by the microprocessor with values selected and entered by the operator.

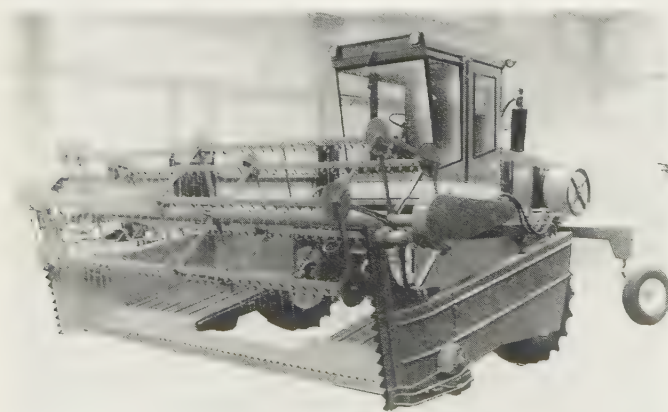


Fig. 14.1 Completely hydrostatic self-propelled windrower with six-bar reel and twin vertical cutter bars, latest in a line developed primarily for use in rape. (*Shelbourne Reynolds SR 2500H 3.66 m (12 ft) cut*)

Though combine harvesters are mostly used to cut and thresh in one operation, they may also often be used to advantage to pick up and thresh crops which have previously been cut and left in the swath or windrow.

Windrow or Swath Harvesting

Windrowing or swathing is mainly used before combining in Britain for crops such as rape, dried peas and herbage seeds, to promote even ripening, hasten drying, or avoid cutter-bar losses by shedding of seed before it is taken into the harvester. In some other countries, notably Canada, its chief use is to avoid losses caused by wind in

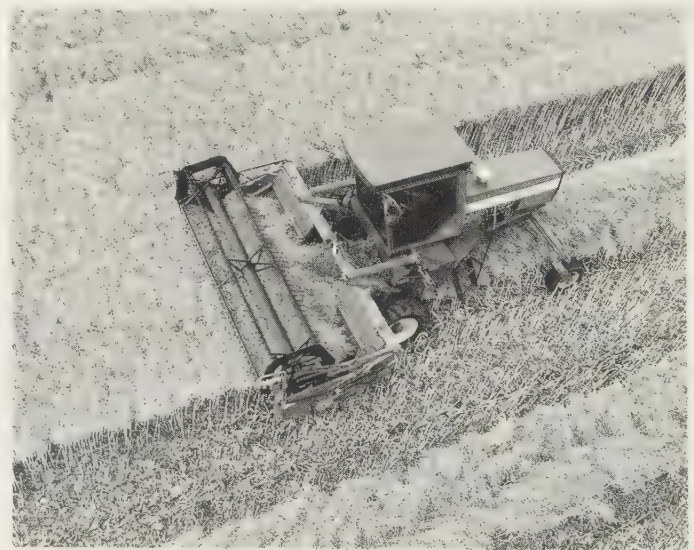


Fig. 14.2 Self-propelled mower-swather with multi-crop use characteristics has hydrostatic steering and transmission. Seen working in ideal conditions in rape. (*Vicon WR 322*)



Fig. 14.3 Draper type windrow pick-up on combine with 'twin-flow' rotary grain separation, working in rape. (Shelbourne Reynolds)

standing cereal crops, to spread the season in which combines may be effectively used, and so to reduce the capital investment in combines.

With either windrowing or direct combining there is inevitably some seed loss where adjacent intertwined plants are separated, even when a vertical knife is used to assist separation. The advantage of windrowing is that the separation is, or can be, carried out at a stage of growth and drying when loss of seed is minimal. With either operation, drying rate after treatment can be fast; so the amount treated by either swathing or chemical desiccation needs to be matched to combine capacity and availability. A draper type pick-up on the combine (Fig. 14.3) can make header losses negligible in swathed crops.

Main types of combine

All combines consist essentially of a cutting or pick-up mechanism attached to a travelling thresher. Simple trailed pto-driven machines with bagging attachment remain of interest in less developed countries where bulk handling facilities are not available. In most developed countries self-propelled tankers have become the most common type; but where windrowing is widespread as in parts of

Canada, trailed pto-driven tankers are popular, and can be effectively and economically operated by modern high-power tractors with their wide range of gears.

This chapter is concerned primarily with existing equipment, but before continuing with the flow of advances in combine harvester development it seems logical to question unqualified acceptance of a specialist self-propelled harvester which in European conditions is generally used for only about 150–200 hours annually. Some of the modern tractors featured elsewhere in this book now have both hydraulic and mechanical power outlets at front, centre and rear in addition to an effective four-wheel-drive. They also have a well equipped cab which can be located, and often is, at the front. It may now be possible for a quite good wrap-round combine to be designed and developed, though most large-scale combine harvester users would be unlikely to contemplate abandonment of their specialist harvesters. Details such as grain tank capacity would have to be related to needed length of rear tractor frame, and probably twin or tandem rear wheels during combine use. The success of reversible consoles in tractor cabs, if needed, is already well proved in some German tractors.

The functioning of a 'conventional' self-propelled combine may be followed by reference to Fig. 14.4. The crop is carried by the auger to the centre of the table, where it is picked up by a chain-and-slat elevator and raised to the drum. Threshing takes place between drum and concave. Long straw with some grain and chaff pass on to the walkers, while grain and chaff that pass through are collected by a grain pan. The mixture of chaff and grain passes to the sieves, where an adjustable blast blows the chaff out of the back of the machine. A return pan brings the clean grain to the grain auger and it passes up the grain elevator to the grain tank. Pieces of unthreshed heads which are not blown out with the chaff and will not pass through the sieves may be returned either to the drum, or on some machines to a special small re-thresher.

The great advantage of the self-propelled machine, apart from the fact that a tractor is saved in a busy time, is that it is able to go straight into the crop without any opening out, and can cut it in the most convenient direction. It also has a large variation in forward speed, usually stepless mechanical or hydrostatic drive, which allows it to deal effectively with a wide range of crops. The driver has a full view of the cutter-bar, and is able to leave laid or otherwise difficult patches if the weather is damp, or

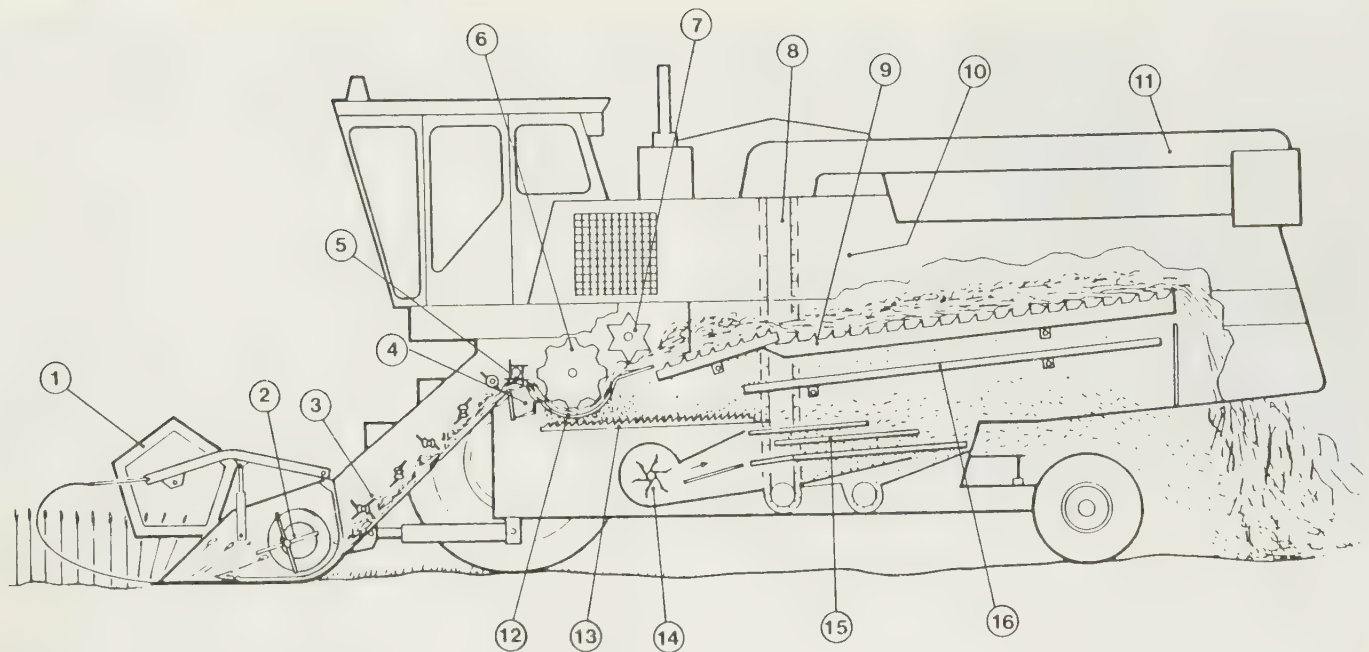


Fig. 14.4 Crop flow through self-propelled combine harvester of 'conventional' layout (*Massey-Ferguson 850/860*)
1 Reel, 2 Auger, 3 Elevator to cylinder, 4 Stone trap, 5 Front beater, 6 Threshing cylinder, 7 Rear beater, 8 Grain elevator

to tank, 9 Straw walkers, 10 Grain tank, 11 Unloading auger, 12 Concave, 13 Main grain pan, 14 Fan, 15 Sieves, 16 Pan under walkers.

to get on with the difficult patches and leave the easier until the crop is really dry.

Great strides have been made on some modern self-propelled combine harvesters in facilitating the many adjustments that need to be made from time to time. Examples include adjustment of concave clearance without stopping the machine; alteration of drum speed during work, by means of variable-speed pulleys that are adjusted by a hydraulic control; independent hydraulic control of both the cutter-bar height and the height and fore-and-aft positioning of the pick-up reel; and an infinitely variable forward speed at full engine speed.

As combine engine power and threshing capacity are stepped up, an option increasingly demanded by users is the ability to stop instantly the flow of crop into the machine if a blockage or breakdown occurs. In a series typical of current trends, an electric fingertip control immediately disengages the table clutch and feed mechanisms and activates reverse drive. This reduces the risk of serious wrapping of crop in the table auger or blockage in the feeder housing, and eliminates need for the operator

to attend to such problems manually. Machines with full hydrostatic drive are widely used: ease of control of forward speed, and good instrumentation of vital components such as drum speed make it easier for operators to pay full attention to aspects such as laid patches needing adjustment of table height and reel settings.

The header

A finger-bar and knife with serrated teeth is almost universal. Such knives will work for long periods without sharpening, and are at their best in cutting dry, upstanding corn; they may compare unfavourably with knives fitted with plain sections when cutting crops containing a high proportion of weeds, or with undersown 'seeds'. The knife usually has a 76 mm (3 in) stroke and is driven via a wobble-gear at about 530–600 cycles/min.

The drive to the knife, reel, auger and elevator can be immediately stopped when required, by means of a foot-operated combined throw-out and slip clutch.



Fig. 14.5 Cylinder separation combine harvester with hydrostatic transmission, environment-controlled cab and electro-hydraulic controls. (Claas UK CS)

The platform is balanced to provide for easy floating at low height of cut. Adjustment is power-operated, by hydraulic cylinders. The range of adjustment for stubble length is typically from about 75 mm to 600 mm (2 ft).

On some machines automatic adjustment of table height is provided. Light skids lying beneath the table operate hydraulic valves which control the lift-and-lower mechanism. The automatic control can be overridden by a manual control for dealing with special needs such as laid green patches.

Modern European machines invariably incorporate a pick-up reel for dealing with laid crops. In recent designs the reel is adjustable forwards, backwards and up or down from the driving platform. In addition, reel speed can be varied over a wide range to match forward speed changes or changes in crop condition.

One design of table incorporates an endless belt assembly between the knife and auger (e.g. Massey-Ferguson 'Power-flow'), which helps to achieve easy transfer from table via auger to the threshing drum. Retracting fingers along the length of the auger are an alternative. Modern wide headers are easily detached and may be towed end-wise on a low-load trailer for road travel.

Threshing

The crop is usually taken to the table centre by large-diameter auger and delivered to the threshing cylinder by

an endless-chain elevator. The drum is normally of beater-bar type, though the peg type is often used for rice. Peg drums, which originated in North America, were discontinued in Europe mainly because of excessive breaking of dry straw, which adds to grain separation problems, makes straw baling more difficult, and absorbs more power. The beater-bar type is also more tolerant of green weeds and damp threshing conditions.

A rear beater is employed just behind the drum to direct straw and grain to the walkers. Most of the separation of grain from straw is carried out by the drum and concave. Front to rear concave clearance ratio is typically $2\frac{1}{2}:1$ with the front adjustable from 1.6–32 mm ($\frac{1}{16}$ to $1\frac{1}{4}$ in). Stepless hydraulic control of drum speed, often in two ranges, and rapid in-cab adjustment of concave clearance are features of most modern machines. Ease and speed of adjustment are vital factors in design of the controls. It is useful if a single hand can be used to vary each of two related functions simultaneously.

A combination of a gearbox and hydrostatic drive can provide a widely variable forward speed suited to both slow work in heavy laid crops and high forward speeds in light standing crops. The main forward speed control



Fig. 14.6 Large-capacity 'conventional' design combine harvester of European origins with very comprehensive electronic monitoring of a wide range of functions and output performances, accompanied where helpful by microprocessor-actuated automatic controls. Some items selected by the operator can be continuously displayed on an eye-level screen. Controls of every kind are electrically operated. A single multi-function lever can control forward movement; cutting height; reel height; and the table throw-out clutch. (Massey-Ferguson 38)

lever needs to be close to the switch for raising and lowering the header. Standards for the location of the main controls could have obvious advantages for users, who typically spend only a small proportion of their annual work time on combining.

Grain from the walkers and from the concave usually passes to two sieves which reciprocate together in opposite directions to improve balance. The upper sieve is generally of the louvred type, with serrated adjustable louvres. An air blast winnows out the chaff, and the grain passes through to a second sieve which may either be louvred or have round holes. Grain passing through this sieve goes to the grain elevator. The material off the top of the sieve passes to the tailings or gleaning elevator, which delivers unthreshed ears or pieces of ear back to the drum.

Mechanisms designed to improve the grain separating efficiency of straw walkers include the 'Cross-shaker' system (John Deere). A reel with curved, oscillating spring tines works above the straw walkers. It provides a lifting and side-to-side action. Another manufacturer (Claas) employs forks mounted on cranks above the shakers to lift and spread the straw.

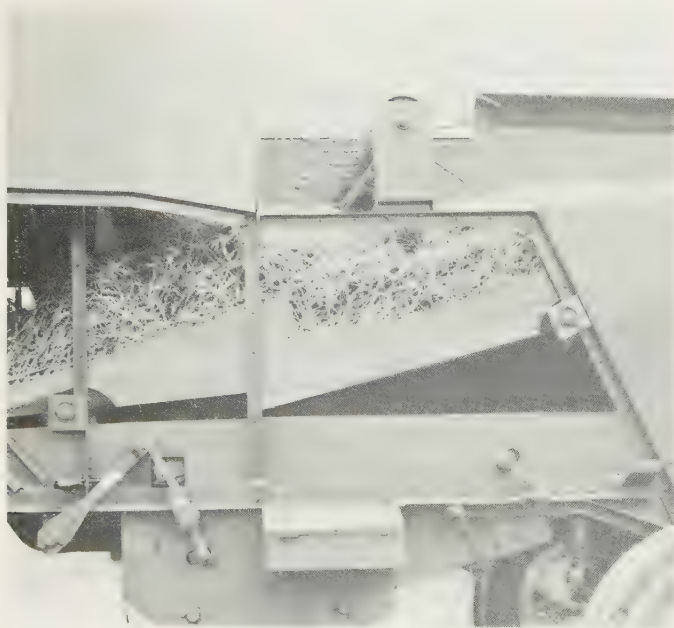


Fig. 14.7 'Cross-shaker' mechanism lifts and spreads the straw to allow grain to fall through it. (John Deere)

Work by Arnold and others at NIAE (now Silsoe Research Institute) provided much basic data on performance of the main components of typical machines. The development of combines with threshing and grain separation by rotary mechanisms indicates that there is still potential for substantial improvement in the basic principles. Objectives include high outputs from machines of small overall size, which can be moved more easily from field to field; and greater independence of variable factors such as hillside slopes. Machines with rotary separation are considered later.

Horizontal auger filling and emptying arrangements also help to ensure complete filling and emptying of wide-based tanks. A typical emptying time for a tank of 5 tons wheat capacity is only about 2–3 minutes.

Hillside and side-hill combines

Hillside combines which can work effectively on very steep slopes (up to 40°) have long been used in some parts of the USA. More recently, the mechanisms that level such machines have been provided with fully auto-

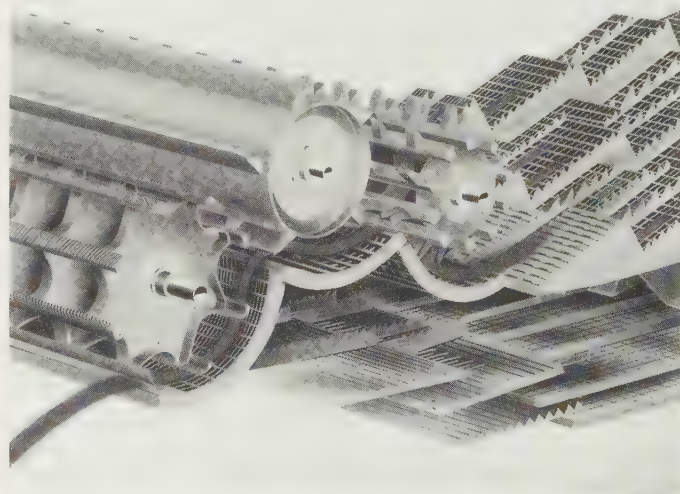


Fig. 14.8 Main threshing and separating elements of combine with large-diameter beater and separator both with their own concaves. This system increases the amount of powered separation between the main drum and straw walkers. (Ford New Holland TX series)

matic control. Machines of European design e.g. Laverda 3300 AL and 3350 AL have automatic levelling controls for across and up-and-down slopes by two separate hydraulic circuits as follows: side-hill to 40%; up-hill to 30%; and down-hill to 10%. All rams have shut-off valves which lock them in position if a hose breaks. Each circuit has its own pendulum and solenoid operated valves. Micro-switches stop oil flow when the above angles are reached.

Some manufacturers (e.g. Ford-New Holland and Claas) have opted for 'internal' levelling or slope-resisting mechanisms for the cleaning shoes on rolling land and not-too-steep slopes in order to maintain outputs. For these gentle slopes, 'lateral float' headers, now standard on a wide range of Ford New Holland TX and TF models, reduce crop losses and give protection against bulldozing.

A simple 'side-hill' type provides a smaller range of adjustment that is suitable for the less demanding slopes on which grain and seed crops are normally grown in Britain. On this type the final drive allows both main wheels to rotate round the axle. The wheels are positioned by linked hydraulic rams, so that as one wheel moves up the other moves down. Transverse slope is detected by a sensor on the main axle, and automatic adjustments are made continuously through electronic switches, hydraulic control valves and the linked rams. The threshing mechanism can thereby be kept level on transverse slopes up to 1 in 5. There is no fore-and-aft levelling in this type. The self-adjusting header and rear wheels follow ground contours. Independent performance evaluation of the side-hill type in barley at 3% grain loss has shown that the output on level land can be maintained on slopes up to about 1 in 6. With the levelling devices not in use, maximum output for the same loss level was reduced to two-thirds of that on level land on slopes of 1 in 10, and to less than one-third on slopes of 1 in 6. Such machines, costing about 40% more than the standard type without levelling mechanisms, can justify their extra cost where a high proportion of fields includes slopes of 1 in 10 or more.

Operation and adjustments (conventional types)

It should be remembered that the rate of combining is governed by the volume of straw handled, rather than by the weight of grain. Almost universal use of sprays



Fig. 14.9 (a) 'Side-hill' combine with provision for automatic levelling on side slopes up to 20% (12° or 1 in 5). Fail-safe outboard disc brakes are fitted. (John Deere)



Fig. 14.9 (b) Lateral float headers are now standard on the New Holland models TX 34H, TX 36, TF 42, TF 44 and TF 46. Crop losses at the header are reduced on hillsides and protection provided against bulldozing. (Ford New Holland)

throughout the developed world has greatly reduced the need to remove green matter from sieves, etc., manually.

On many farms where weed control is good there is practically no greenstuff to hinder the work, and in such conditions the combine can often achieve both a high output and a storeable sample direct from the machine.

There is full justification for starting to combine crops such as barley as soon as the grain is reasonably mature. Malting barley varieties are bred to be low in nitrogen

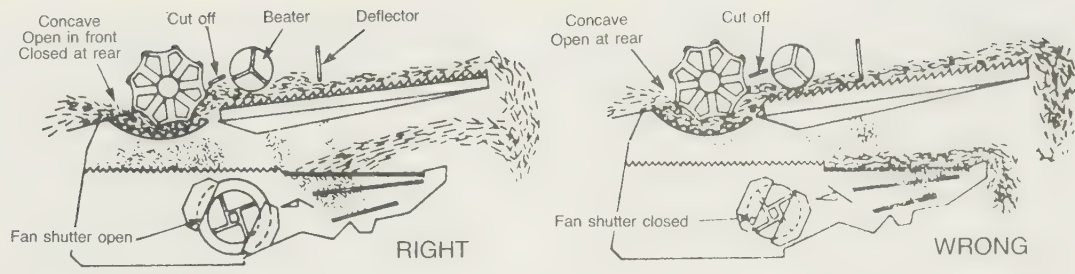


Fig. 14.10 Combine harvester adjustments: general principles.

content before full ripeness; and quality is not impaired by early harvesting. Some extra grain drying cost is usually more than compensated by timeliness of autumn sowing. Crops that ripen irregularly (e.g. clover, peas, linseed, rape, mustard) are often better windrowed; but there are conditions where use of a growth-regulator type 'desiccant' can provide a satisfactory direct combining alternative at lower cost. Table 14.1 shows the generally preferred methods for handling various types of seed crop by combine. Detailed settings suited to individual machines are suggested in manufacturers' instruction books.

Header adjustments

Incorrect setting of the pick-up reel can lead to severe header losses, particularly in laid or over-ripe crops. Both speed and position of the reel need adjustment to suit the crop, and considerable experience and judgement are necessary, particularly if the crop being harvested is very variable. As a general rule, in laid crops, the reel should be set well forward with the tines just brushing the ground when the cutter-bar is about 75 mm (3 in) above the ground level. In standing corn the reel should generally be set so that the tine support bars strike the crop about 150 mm (6 in) below the ears. If the tines are inclined slightly away from the combine, any tendency to wrapping is usually reduced. If on close examination grain is being knocked out of the ears, reel speed should be reduced: a simple matter with most modern machines. Where crop lifters are fitted their points should just touch the ground and the reel should be set back to pick the crop off the

Table 14.1 Harvesting Seed Crops by Combine

<i>Crop</i>	<i>Generally preferred method of harvesting by combine</i> <i>* Use of stripper</i>	<i>Notes</i>
Cocksfoot and fescues	Windrow and pick-up or direct-combine <i>* Direct strip good except long green laid</i>	Medium drum speed and concave clearance. Very light wind. If windrowed, difficult to pick up. If direct-combined, risk of serious loss by shedding, and trouble due to green seeds.
Ryegrass	Usually direct-combine. <i>*Direct strip good in dry crop</i>	High drum speed, small concave clearance, and light wind.
White clover	Windrow and pick-up.	Filler plates needed. High drum speed, very small concave clearance and light wind. Clover sieves needed. Thresh when perfectly dry. Watch for splitting of seed. Can occasionally be combined direct.

*For grain stripping see pages 234–5

Table 14.1 *continued*

<i>Crop</i>	<i>Generally preferred method of harvesting by combine</i> <i>* Use of stripper</i>	<i>Notes</i>
Red clover	Direct-combine unless heavy, leafy crop.	Adjustments as for white clover. Windrow if a heavy, tangled crop.
Timothy	Windrow and pick-up.	Adjustments as for clovers. Threshing is difficult, and rethreshing is sometimes worthwhile.
Mustard, rape, swede, turnip	Windrow and pick-up or direct combine.	Medium drum speed and concave clearance. Light wind. Avoid splitting seed.
Linseed	Direct combine if clean. * Direct strip easy if clean, ripe and dry	Medium drum speed, small concave setting, medium wind. Leave till dead ripe. Watch for leaks and stop up with plasticine. Windrow if much green rubbish.
Sugar beet and mangold	Windrow and pick-up.	Low drum speed, wide concave clearance, medium wind.

tops of the lifters. Leaving a long stubble eases the work of the combine in many ways. On most combines it is straw walker capacity that limits work rate, and it is losses here that become serious if an attempt is made to deal with too much straw. With upstanding crops it is generally advisable to keep well above any weeds or undersown leys.

Crops such as peas and beans are much more easily damaged than cereals, but even with a crop like wheat, damage that is difficult to detect with the naked eye can

result in lowered germination. Damage is apt to be particularly severe if the threshing is carried out at moisture contents outside the usual limits of about 15 to 21% moisture. Crops severely handled during harvest are much more likely to deteriorate during subsequent storage than crops more gently handled.

When adjusting any particular component of a combine harvester, the effect on other components needs always to be borne in mind. Any unnecessary severity in the action of the drum will tend to overload the separating and cleaning mechanisms by creating more broken pieces of straw; and any adjustment of the chaffer-sieve will influence the tailings return, as well as the cleaning on the shoe sieves.

Losses from combines may be serious unless a constant watch is kept for signs of unsatisfactory threshing. If a combine is correctly set, excessive losses of seed over the back generally indicate that the threshing and separating mechanism is being asked to operate beyond its capacity, and a reduction in forward speed will usually reduce such losses. Losses are often expressed as percentage of grain taken into the combine, but care needs to be exercised when studying test reports to relate the percentage loss to the crop conditions and farming needs. For example, a 1% loss in a crop of 7.5 tonne/ha, (3 tons/acre), viz 75 kg/ha (67 lb/acre) is about as high as most farmers would consider acceptable in good harvesting conditions in Britain; but loss above double this may sometimes have to be accepted. Comparisons of combine capacity at the Prairie Agricultural Machinery Institute in Canada are often based on 3% loss. As a guide, one wheat or barley kernel per 0.09 m² (1 ft²) is equivalent to a loss of about 4.5 kg/ha (4 lb acre); in using this figure it should be remembered that most of the losses will be concentrated in a narrow swath behind a combine which has cut a much wider swath.

Grain loss monitors

These may be used to provide an indication of changes in rate of loss. Most monitors have ultra-sonic sensors that detect the sounds of grains striking them. These sounds are registered electronically, and displayed as a meter-reading in front of the driver. Such instruments are of use mainly as indicators of the point where loss increases disproportionately with increase of forward speed. It should be noted that unless a correction is applied, an

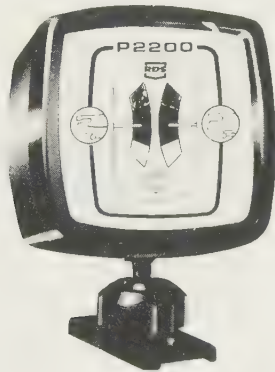
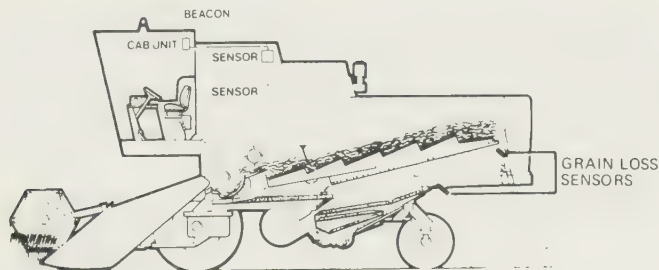


Fig. 14.11 Combine harvester grain loss monitors and tank alarm signals. (RDS)

Above: Layout of loss monitors on a conventional combine, and of tank alarm sensors. The tank sensors are of diaphragm pressure type; they activate audible and visual in-cab warnings in addition to the full-tank flashing beacon.

Below: Combine performance monitor. The instrument shown incorporates a double meter which simultaneously but separately monitors and displays losses behind both sieves and walkers. The instrument is linked to full-width ultrasonic sensors.

increase in forward speed at a given rate of grain loss per unit area will normally result in a higher meter-reading, simply because more area is being covered in a given time. Monitors built into sophisticated combine harvesters by the manufacturer can give an accurate indication of area covered provided that the operator maintains a constant cutting width. They can also display changes in grain-loss adjusted automatically for change in forward speeds, and compute grain outputs provided the appropriate calibration constant for type of grain is used. The result should be that a good operator is supplied with output and loss information adequate to ensure that an

expensive machine can always be set to work at somewhere near its potential performance.

The moisture content of grain threshed by the combine varies greatly, according to the state of maturity of the crop and the conditions in which it is harvested. Conditions required for safe storage, together with the construction and operations of grain driers are dealt with in Chapter 18.

Combines with rotary grain separation

Axial-flow threshing

One type of rotary separation thresher (e.g. Case-International) utilises, behind a conventional header, an inclined rotor located in the centre of the harvester with its axis parallel to the direction of travel (Fig. 14.12). At the lower end of the rotor impeller blades gather the cut crop from the feeder housing and deliver it to the threshing zone of the rotor in which rasp bars on the rotor periphery work against a wire and bar concave similar to that used in conventional machines. Axial movement of the crop is achieved by interaction of the rasp bars with helical guide vanes situated above the rotor on the inside of the casing. The cylinder needs to be kept fairly full, and threshing takes place gradually, a single ear typically passing round the threshing part of the cylinder two or three times along a spiral path. The open-grate construction allows grain to pass through the concave as soon as it is released. Separation is completed in the rear half of the housing, where the separating area occupies more than a semi-circle. Concave clearance is set manually to suit the crop and variations in threshing conditions are then catered for mainly by adjustment of rotor speed and forward speed from the driver's seat. A two-speed gearbox added to variable-speed V-belt drive can provide rotor speed variation from about 300 to over 1400 rpm.

Augers running beneath the rotor deliver the grain and chaff to sieve separators of conventional type, and tailings are delivered back for rethreshing.

This type of grain separation mechanism occupies much less space than conventional straw walkers and is clearly less susceptible to external influences such as sloping land. The threshing by multiple rubbing can be less violent yet more thorough, and the absence of reciprocating walkers reduces vibration and noise of the whole

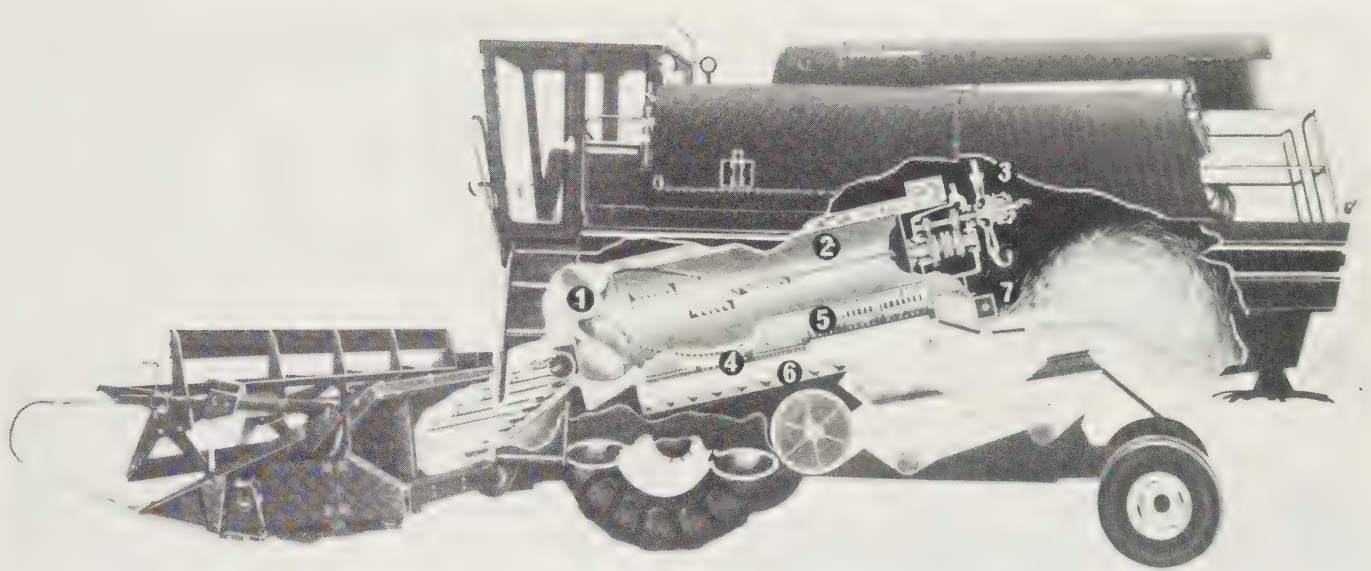


Fig. 14.12 Sectional view of 'axial-flow' rotary separation combine harvester. (*Case-International*)

1 Impeller, draws crop and air into rotor, reducing dust at feed end, 2 Axial-flow rotor moves crop spirally rearward. Speed of rotation adjustable on-the-move by fingertip electrical switch, 3 Rotor drive. Torque-sensing device automatically regulates

belt tension in relation to load, 4 Concave. Clearance adjustable by ratchet, 5 Separating grate continues grain separation, 6 Grain pan. A series of side-by-side augers moves grain continuously to sieves, 7 Discharge beater propels straw rearwards.

machine. Monitoring instruments provide for total engine torque sensing and a digital read-out of engine, rotor, fan and forward speeds.

The axial-flow system has made a big impact in North America but has not been widely accepted in Europe. Equally important developments with similar objectives include those based on use of a conventional drum and concave followed by use of rotary separation mechanisms in place of straw walkers.

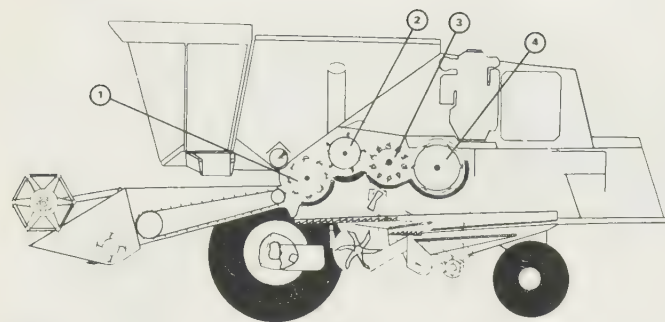
Rotary separation systems (tangential)

Rotary separation systems have been developed to replace straw walkers after primary threshing in a drum and concave of conventional beater-bar type. Tests show that grain losses of well developed and correctly adjusted rotary separation machines can increase much less markedly than those of comparable straw walker machines as output is pushed up by increase of forward speed. This

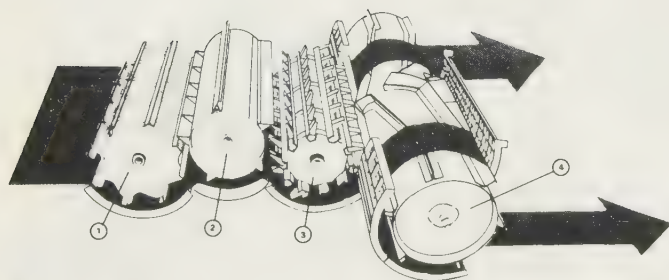
makes it possible with good instrumentation to operate near the limit of engine power without serious increase in grain loss. It is convenient to consider two commercially available types separately, since the methods of primary separation and cleaning are quite different.

'Twin-flow' system (New Holland TF)

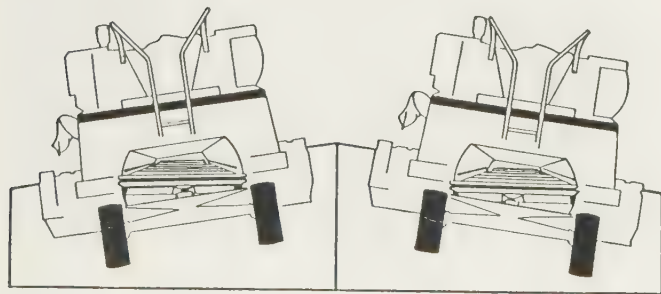
A well-proved combination of (a) drum and concave; (b) powerful rear beater and (c) rotary separator with concave, is redesigned; and a component called a 'twin-flow' rotor added to thin out the crop laterally within a very short space compared with the use of straw walkers. The design allows drum speeds to be lowered, leading to reduced grain damage. The simplicity of the basic grain/straw separation design and small space occupied by the major components permits redesign of the cleaning system – necessary because the primary separation produces many short pieces of straw which must first be disposed of. A powerful air blast is employed in con-



(a)



(b)



(c)

Fig. 14.13 'Twin-flow' Separation system. (Ford New Holland TF)

(a) Diagram shows crop flow through threshing drum 1, beneath rear beater 2 and rotary separator 3, to twin-flow rotor 4. Grain pan, fan and sieves are built as a single laterally self-levelling assembly, pivoting at front and rear.

(b) The straw layer is thinned by diverging vanes on the twin-flow rotor, while remaining grains are separated by centrifugal force. The design allows lower threshing speeds with high separation efficiency.

(c) The swinging cleaning shoe stays level on side slopes up to 1 in 6 gradient, allowing low losses to be maintained at high outputs within this range.

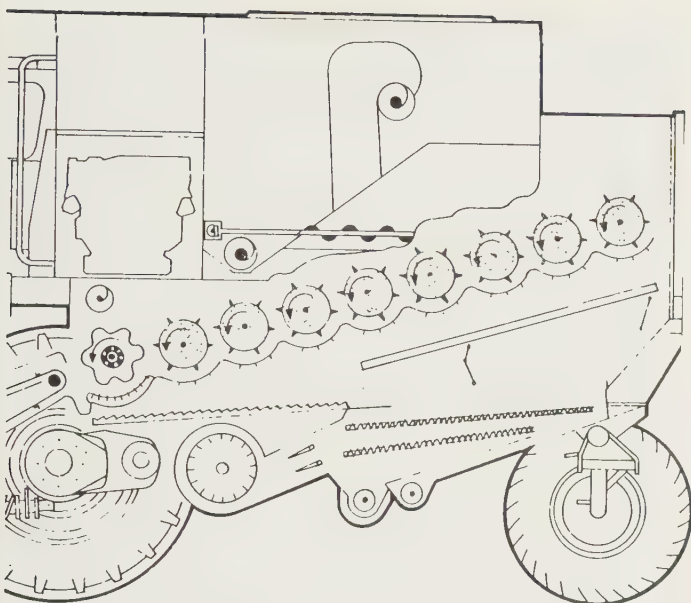
junction with a pre-cleaning sieve to get rid of most of the light straw and chaff before the grain reaches the conventional sieves. A major advance is achieved by making the complete cleaning unit, consisting of grain pans, sieves and fan, self-levelling on side-slopes up to 1 in 6. The whole compact separation process has been found capable of high output at low grain loss in a wide range of conditions in Britain.

Cylinder separation (CS) system (Claas)

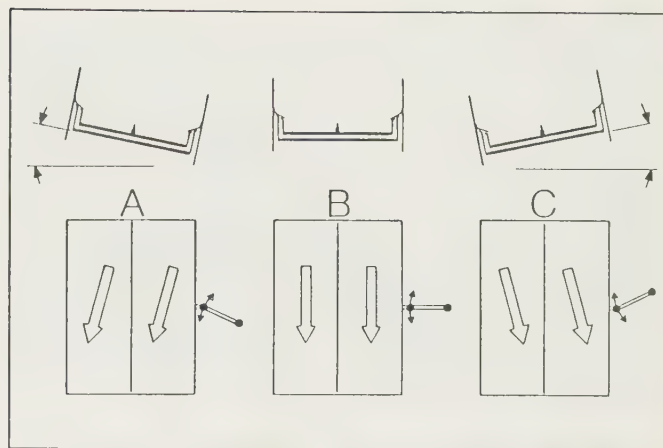
After primary threshing by conventional drum and concave, separation from straw takes place in a line of eight cylinders, each with speed and concave clearance adjustment. The cylinder separation, relying primarily on centrifugal forces, is unaffected by side slopes. The Claas 3-D system has been introduced to assist a standard sieve arrangement to maintain performance on slopes. An undriven articulated pivot-arm link is attached to the centre of one side of the sieve (Fig. 14.14). The position of its remote end is automatically controlled by a vertical cylinder housing a pendulum which causes hydraulic oil flow to adjust the position of the outer end of the pivot arm. On flat land with the pivot arm at right angles, its effect on sieve motion is negligible; as its angle is changed by a side slope, the effect is to increase the anti-gravity action and to throw the grain from the lower edge of the sieve towards the upper edge. The throw increases with the angle, so maintaining sieve performance within the limits of adjustment.

Capacity of combine harvesters

Experience has shown the difficulty of giving a figure for combine harvester capacity that is of general use in Britain's widely varying conditions. Capacity is usually best reckoned in terms of tonnes/hour, but the figure for grain alone means little, since it is usually the machine's capacity to deal with more straw that limits output. Thus, when combines are tested, the straw must be passed through the machine at a high rate, and capacity is expressed as maximum throughput of MOG (materials other than grain) at the point when grain loss is acceptable, e.g. 1%. If the machine is then driven faster, the usual result is that more grain is carried over the walkers with the straw, and loss of grain rises steeply.



(a)



(b)



(c)

Fig. 14.14 In-line 'Cylinder Separation' (CS) System. (Claas UK)

(a) General arrangement: each cylinder has its own concave and four speed adjustments.

(b) Diagram illustrating action of optional 3D cleaning system for use on side slopes: A left-up slope, B level, C right up-slope. Arrows show direction of grain throw (up the slope) on the sieve.

(c) Optional hydraulic levelling rams for uphill work shown extended. The levelling frame can raise the rear when travelling uphill by up to 11 degrees, equivalent to remaining level on a 1 in 5 slope, and can lower it by $2\frac{1}{2}$ degrees when descending.

Grain capacity in the rating run equals

$$\text{straw output} \times \text{grain : straw ratio.}$$

Thus, for a combine with 10 tonnes/h straw output at a given percentage grain loss, in a typical wheat crop with a grain:straw ratio of 1:1, the rated grain output is 10 tonnes/h.

In barley, a typical grain : straw ratio is 1.4 : 1, and with a straw output of 10 tonnes/h in the rating run, the rated

grain output might be $10 \times 1.4 = 14$ tonnes/h. The rating run capacities are appreciably higher than the average outputs that can be expected in normal working conditions.

The seasonal capacity of a combine depends on a wide range of factors, chief of which are policy as regards the required grain moisture content at harvesting, and the weather conditions of the area and of the particular season.

Most farmers are now equipped to deal with a considerable amount of grain at moisture contents up to

about 20%; and because of the importance of timeliness of autumn cultivations and sowing already mentioned, it is no longer most economic to delay the start of harvest until the grain can be brought in at a safe storage moisture content without the need for drying. On this basis there are usually at least 150 and often 200 hours of good combining weather during the normal grain harvest period; so a machine with an output of 10 tonnes per hour should be able to handle at least 1500 tonnes and up to 2000 tonnes in a normal season.

Equipment for bolting on to tanker combines to measure work rates, areas worked and yields from individual fields is briefly described in Chapter 18.

Grain stripping by SRE stripper

This section deals briefly with progress and potential of the stripper header pioneered by NIAE (now Silsoe Research Institute) under the leadership of Wilf Klinner, and currently manufactured on a commercial scale by Shelbourne Reynolds. During the development period it has become increasingly clear that when harvesting cereals and a few other crops, reduction of straw intake to the combine harvester can be an economic way of increasing harvester outputs. Stripper headers for interchange with conventional types were first sold on a small scale in 1988 and used with generally good results. By 1989 progress accelerated and monitoring confirmed reduction of straw

intake in standing cereals of up to 80%, linked to grain outputs up to 40 tons/h.

In cereals the stripper header gave greater output advantage to combines with rotary separation, the difference being attributed to the adverse effect of a high proportion of stripper-transferred flag leaf on straw walkers. The simplicity of the basic stripping mechanism is indicated by the diagram in Fig. 14.16. The eight-bladed steel rotor has mounted on it eight rows of plastic stripping fingers profiled approximately as inset. Rotor speed is variable from 300–1000 rpm in steps dependent on crop type. The combs carry out the dual functions of grain stripping and conveying of both grain and heads. Detailed design of stripper fingers continues to attract attention. Emphasis is placed by Silsoe Research Institute on the potential merits of threshing by the stripper rotor itself, and advantage that might be achieved by not passing already threshed grain through a threshing drum in the combine. The current hood shape is designed to provide positive crop flow and minimum grain losses. Speeds of rotor and auger are monitored, and a buzzer warns if speed of either falls off by a pre-set proportion. Main operational problems are with laid long green crops, but work rate tends to suffer more than grain loss. High forward speeds can be employed in standing crops on flat land. Straw disposal can be tackled in various ways. Use of a wide cutter-windrower followed by a big-baler can result in speedy straw clearance on a large scale.



Fig. 14.15 Ford New Holland TX 36 with Shelbourne Reynolds 5.4 m Stripper Head working in wheat. (Shelbourne Reynolds)

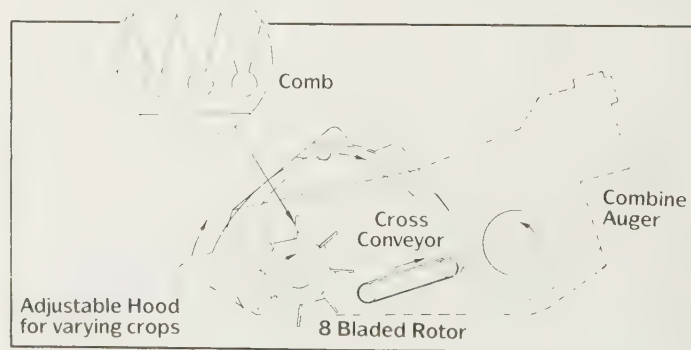


Fig. 14.16 Vertical longitudinal section of stripper head with (inset) profile of plastic comb fingers attached to octagonal steel rotor. (Shelbourne Reynolds)

Grain stripping development trends

Development projects on commercial expansion of stripper use begun by co-operation between Silsoe Research Institute and Shelbourne Reynolds included on-farm trials with a prototype tractor trailed stripper unit, put together by Kidd Farm Machinery, on the basis of a trailed stripper unit operated by a 75 kW tractor, using a conventional thresher unit and a grain tank of 4 tonne capacity. The market envisaged was fairly small mixed farms. One of the objectives soon became trials on the practicability of mounting a cutter-swather behind the stripper header with a choice between windrowing the straw for baling, or chopping it for easy incorporation.

Combine cabs: operator health aspects

Working in a dusty atmosphere when harvesting or handling hay or cereal crops can result in either severe discomfort or serious illness in some workers. Research has confirmed that both mechanical irritation of sensitive areas of the nose, throat and lungs and biological factors concerned with inhalation of fungal spores may be involved. Enclosed cabs on the more expensive self-propelled combines are therefore a logical development, and their needs include not only effective control of temperature, maintenance of good vision and noise reduction, but also removal from the air in the cab of dust particles and spores down to a size of about 0.5 microns. This means in practice that cabs must be reasonably well sealed and maintained at slightly above atmospheric pressure by a fan that draws its air supply through a large-capacity filter. Some evaporative cooling is an advantage in the hottest weather. About 20% of demand in Europe is for combines without cabs.

With less expensive machines a low-cost solution of the dust problem is provided by a suitable dust-protective helmet (e.g. Racal 'Airstream'). This lightweight helmet with rechargeable battery-operated fan and an effective filter does not depend on a close fit to the facial contours, does not cause any resistance to breathing, permits talking, and is reasonably comfortable to wear in working conditions. Independent tests have proved effectiveness in screening out dust down to the size of cladosporium spores. Such a helmet has the advantage of being usable for a range of farm tasks, including work in farm grain stores.



Fig. 14.17 Grain emptying on the move, using tandem axle tipping trailer. (Ford New Holland photo)

Grain handling

The grain is normally delivered from a grain tank mounted on the machine into a tipping motor lorry or trailer which can tip its load at the buildings without the necessity of employing any hand labour. Where a tractor and trailer are used for bulk grain transport it is usually convenient to have two trailers, one of which can be left at a corner, handy for the combine.

Modern high-capacity combines can pose a difficult handling problem where transport or reception facilities are inadequate. The tank on the machine normally needs emptying about every 20 minutes, and the quantity may be over 5 tonnes. Delivery, which can be done on the move, takes about $2\frac{1}{2}$ minutes. The loads must therefore be emptied rapidly and little time lost on transport if the combine is to be kept at work. A tipping lorry with a body of above 6 tonnes capacity can serve two fairly large machines at up to 2 miles from the drier, but it is advisable to set down a spare trailer or two to act as an extra container if the transport is held up.

Handling of the straw

There is great diversity of practice in the handling of straw left by the combine. Burning has become increasingly unacceptable, mainly on account of local atmospheric pollution but also from a general environmental point of view. Many potentially profitable off-farm uses have been

explored, but most which might make a substantial impact have emphasised the low value of straw in relation to such aspects as cost of packaging and transport. Interest therefore tends to be concentrated on a search for low-energy methods of incorporation which permit early autumn drilling and also encourage rapid decomposition in the soil.

Some general aspects of incorporation of straw in the soil are considered in Chapter 3. A short chop makes all incorporation tasks easier and more effective. The logical place and time for chopping are as the straw leaves the harvester, but there can be disadvantages: a chopper on the combine typically adds about 15% to the engine power required. This, however, is roughly equal to the power for grain unloading, so users who prefer stationary unloading may not need a higher-powered engine. Operational extras of a combine-attached chopper include attention to deflector plate angles and to avoidance of spreading the chaff on laid crops and recirculating it over the sieves. There is always some difficulty at corners, and MOG from sieves tends to remain in a narrow band.

Tractor-mounted choppers include well-proven types with high-speed horizontal rotor carrying swinging knives between banks of stationary interceptor blades. Adjustable vanes assist wide and even distribution. This type has the advantage of shortening the stubble. A second type employs a slow-rotating pick-up with backward-inclined tines which deliver the windrow to a separate high-speed chopping rotor. Advantages are much less trouble from stones lying on the surface and a modest

power requirement. Stubble trimming over the full header width is allowed for on some combines; the optional attachment is mounted behind the table and follows ground contours.

On many farms the straw is needed for feeding or for litter and must be collected. By far the most popular method is to use a pick-up baler. Bale handling equipment described in Chapter 13 may be used to lighten and speed up the work. When the straw is in good condition it should be carted as soon as possible, since a long delay usually results in it being partially spoiled by rain.

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Root Harvesting Machinery

Potato lifting

The conditions in which potato harvesting implements and machines have to work vary widely. Sometimes the soil is friable and stone-free, and separation of the potatoes from the soil and from their tops is a fairly simple matter; sometimes the soil is dry and stony or cloddy, and there is a choice of methods of separating the potatoes from the contaminant; and sometimes the soil is wet and sticky, and conventional mechanical separation mechanisms rapidly become coated with wet soil and cease to function effectively.

Choice of potato harvesting equipment must therefore depend primarily on working conditions and secondarily on the acreage to be dealt with, capital that can be invested, etc. In the past, much effort was devoted to 'work study' aspects of picking potatoes by hand. This directed attention to such aspects as the advantage of putting two rows into one, and the benefit with small gangs of digging the required number of rows beforehand, working along the rows and keeping a transport vehicle well up to the pickers.

Today, even on difficult soils, an objective must usually be to get rid of the stooping and lifting involved in hand picking, and there are simple rear-mounted harvesters to facilitate this where the area grown is fairly small; but hand picking after lifting by elevator-digger remains an acceptable system on many small farms. Developments in stone and clod windrowing discussed in Chapter 7 have so transformed the potential of unmanned harvesters on light-textured soils that increased use of such machines is certain, any hand sorting needed being more easily carried out on stationary machinery at or near the store.

Avoidance of damage to the potatoes by bruising or cutting them is an essential requirement for British conditions, whether the crop is required for immediate sale



Fig. 15.1 Semi-mounted two-row elevator digger fitted with belt-type chain for lifting an early crop. Mid-mounted castor wheels facilitate short turns. (Blair Engineering/Ransomes)

or for storage. This is a factor which needs attention when choosing harvesting equipment, and also when using it.

The conventional type of *potato spinner* has a strong wide share that passes beneath the potato rows and completely loosens the soil and tubers; it is followed by revolving digging forks, which throw the soil and tubers sideways. In 'direct action' diggers, the forks are attached directly to the revolving shaft. Some diggers employ a linkage that keeps the revolving forks always in a vertical or nearly vertical position and produces a 'feathered' action. The exact angle of the forks may be varied by adjusting the link gear.

Another type of digger has the main spinner rotating on a nearly vertical axis, and an auxiliary spinner which helps to separate the tubers from haulm and soil.

One type of 'spinner' employs a disc-shaped 'spider' with curved tines, running almost flat, just behind the share. This type of mechanism sometimes provides the primary separation on more complex harvesters.

The basic types of spinner, even with pto drive, cannot be considered competitive with chain elevator diggers on account of more bruising of tubers, loss from crop not left on the surface, and higher labour need for picking.

Elevator-diggers

The elevator digger consists essentially of a broad share, behind which rises a metal elevator chain composed of parallel links, running on agitator sprockets. The soil is shaken through the links of the chain web, and the potatoes are delivered at the rear of the machine in a narrow row. The agitator sprockets can be changed to give more or less shaking, according to conditions. Modern machines are all pto-driven, and this permits some variation of speed of the chain in relation to forward travel. Two-row elevator diggers have several advantages. The amount of damage to soil structure by tractor wheelings during the lifting operation is halved; the potatoes may in suitable conditions be put into a single row, thereby facilitating picking; there is less opportunity for tubers to be damaged by share edges and the ends of elevator rods; and the digger can work ahead of the pickers to any extent desired.

Where abrasion is particularly severe with the hook-link type of web, it may be worthwhile to use a 'Continental' type of web with the flattened ends of the rods attached to endless belts. This type of chain costs more, but is cheaper to maintain.

Elevator agitation should always be the minimum necessary to free the potatoes from most of the soil. Excessive agitation bruises the potatoes and results in more wear and tear of the machine.

With some machines it is possible to run the elevator chain in either one or two sections. In good conditions it is best to have the web in one piece, but in wet and sticky conditions better separation may sometimes be achieved by splitting it into a long front part and a short rear section.

The chain web should be run fairly tight, and excessive

slackness caused by wearing of the links should be remedied by removing links. The web, rollers and agitators should not be lubricated, but all rollers should be inspected occasionally to ensure that they are rotating.

If the soil is very easily separated and the potatoes are being bruised, the front agitators should be replaced by plain rollers, and the front roller set as low as possible. On heavier soils in wet conditions, where separation is difficult, the front roller should be set fairly high, to break up the ridge immediately it comes to the elevator.

Windrow harvesting

Windrow harvesting of potatoes has long been practised in some parts of Canada and USA, e.g. Red River Valley, where potatoes are grown on heavy silty soil that does not readily come off the tubers until some drying has occurred. Similar conditions can occur on some English fen soils after irrigation. A machine that is basically the lifting and soil separation part of a conventional two-row harvester has been assembled by Standen into a simple arrangement to put two rows into a narrow windrow. This (Fig. 15.2) has been found an effective stage I



Fig. 15.2 Stage 1 of windrow harvesting potatoes in Eastern England. A heavy growth of tough previously sprayed haulm is being treated by a front-linkage mounted hydraulically powered two-row Standen flail toppler which incorporates a side conveyor belt to deliver the chopped haulm into the tractor wheel marks. The two-row potato windrower leaves the crop in narrow windrows which after a few hours drying can be picked up fast by a two-row unmanned side-loading harvester which has its intake suitably narrowed and adjusted to a shallow depth and gentle slope. (*Standen Windrower*)

windrower, often needing only a few hours of drying before use of a standard two-row side-loading harvester with only slight modification of the share and set for minimum agitation can be used for high-speed unmanned harvesting.

Complete potato harvesters

On many British soils such as the Black Fens, light loams and silts and some sandstone soils, where there are few or no stones, complete harvesters can often be effectively used to deliver the crop directly into a trailer or other bulk container, or into bags, without hand sorting. On more difficult soils, where it is necessary to sort the tubers from stones or clods, machines which will do most of the sorting have been developed. Some machines designed for use in very difficult soils aim to provide conditions which enable pickers to do effective manual sorting on the harvester. Others are designed to do the sorting by means of mechanical devices which operate with a minimum of supervision. Stone windrowing, dealt with in Chapter 7, can be effectively used on many light soils to provide harvesting conditions suitable for the use of simple unmanned two-row machines. These have the



Fig. 15.3 A one-row trailed potato harvester with offset lifting; through-flow haulm separation assisted by spring-loaded rubber fingers; picking table with separate stone and clod conveyor; bunker hopper with hydraulic vertical lift, and unloading-floor conveyor drive. Low draught, good manoeuvrability and minimal tuber damage are reported by users. (Standen/Wuhlmaus (*Sabre TF*))



Fig. 15.4 Offset single-row harvester with stone separator attachment (brush type) and picking-off platform. Machine is shown opening out, using trailer-loading elevator. (Pearson/Grimme 'Row-over')

advantage of a high potential work rate. The main factors involved in classification of types of harvester are:

- Manned or unmanned
- Number of rows worked (usually 1 or 2)
- Tractor-mounted, trailed or self-propelled
- Bagging, side-delivery or bunker

The simplest harvester is in effect little more than a side-loading elevator digger: but the most complex types rely on many automatic sorting devices.

Good control of share depth is essential. One way of achieving this is by means of an automatic hydraulic servo control mechanism, working via a pneumatic-tyred gauge wheel or a 'Diabolo' roller that runs on top of the ridge.

Typical machines incorporate a primary separating mechanism similar to that of a chain web elevator digger.

Unmanned two-row harvesters

Rapid development of use of unmanned two-row trailed harvesters has been facilitated by effective techniques

and equipment for stone and clod windrowing and by stationary large-capacity cleaners with good arrangements for removal of substantial amounts of soil at or near the store. Outputs of 8 to 20 t/h may need to be handled. Many important details of harvesters have been redesigned to provide adaptability to soil conditions, freedom from blockages, durability, avoidance of damage to tubers, and ease of control and adjustments from the tractor cab.

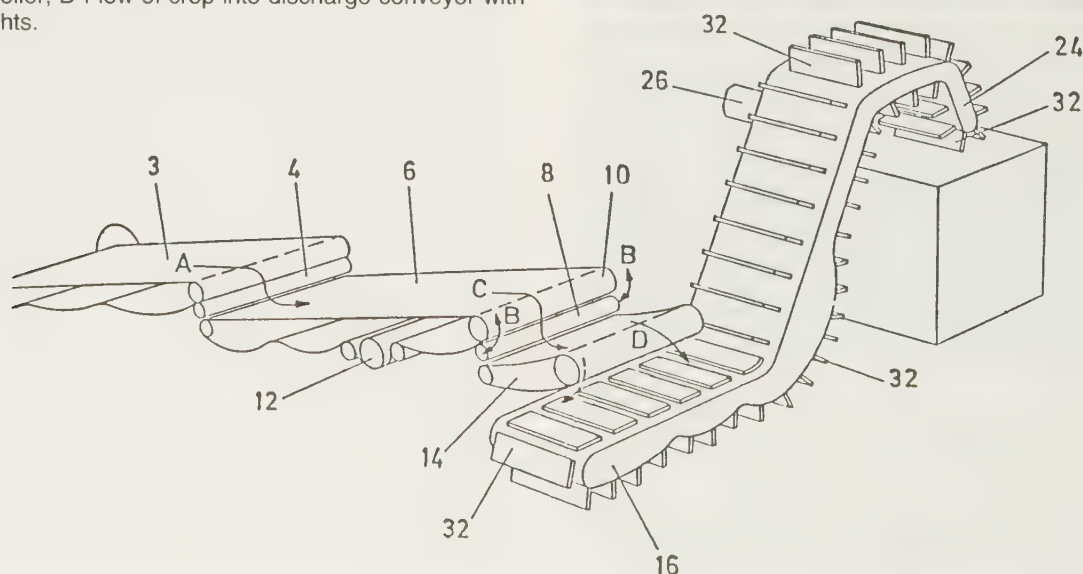
Features include: an improved type of 'Continental' web has the ends and centres of the straight cylindrical rods securely fastened to substantial belts; a new form of drive by the full width of rubber-covered drums gives quiet, positive operation, permits easy change of web spacing without need to remove drive rollers, and provides a better surface for operation of full-width rubber-covered contra-rotating haulm extraction rollers at the rear ends of the webs. Curved spring-steel strips or other spring-

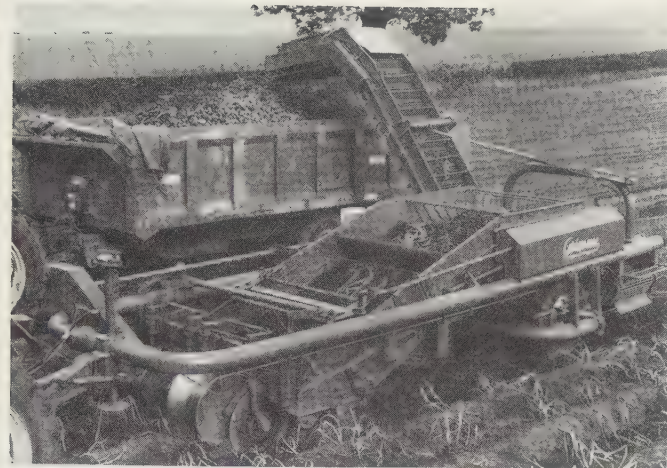
mounted suspended devices help to press haulm on to the extraction rollers without impeding crop flow. Electro-hydraulic control of agitators below the webs allows rapid adjustment from the cab to suit changes of soil conditions often encountered within the length of a single row. Provision of an adjustable above-web oscillator can help to spread soil, haulm and weeds and thereby assist performance of the haulm removal rollers, and these can help to smooth the passage of crop to the next web or conveyor.

Modular designs are employed to permit choice or change of final separation equipment used in the field, including the option of some hand work on the machine. Discharge elevators include a variety of features associated with a chosen folding system, provision of a picking platform, and minimisation of damage to crop in transfer on to the cross conveyor and delivery to the trailer.

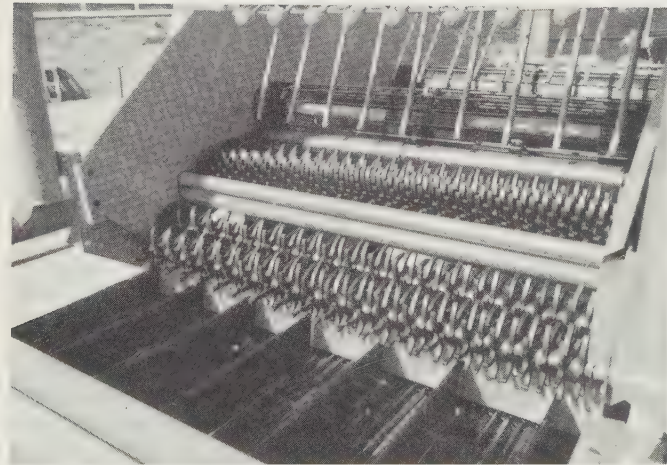
Fig. 15.5 A two-row side-loading potato harvester, usually unmanned. Diagram shows general arrangement of some features. (KeyAg 'Conqueror')

3 Primary digger web, 4 Haulm extraction roller, 6 Secondary digger web, 8 Haulm and clod extraction roller, 10 Plain roller, 12 Drive sprockets for secondary web, 14 Rear delivery web, 16 Flighted discharge conveyor, 24 Swan-neck end of discharge conveyor, 26 Folding flights in elevating position, 32 Folding flights in elevating position, B Flow of haulm and clods into second extraction roller, C Flow of crop over roller, D Flow of crop into discharge conveyor with laid down flights.





(a)



(b)

Fig. 15.6 A two-row potato harvester, usually unmanned but with pick-off platform option not shown. (Pearson/Grimme 'Q Continental')

(a) General view showing tubular main frame and elevator which folds within frame width for transport.

(b) Star cleaner module to improve cleaning between second web and elevator.

Electro-hydraulic steering of the harvester can assist in avoiding the effects of crabbing on hillsides and in providing short turns at headlands. Overall lightness and generously sized tyres can help in continuing work in wet conditions. An important control need is good visibility of the main operations from the tractor cab.

Setting of the haulm removal rollers needs under-



Fig. 15.7 A two-row self-propelled side-loading multi-purpose potato, vegetable root crop and bulb harvester. The 70 kW hydrostatic drive power frame has drive wheels of adjustable track width and is shown with front-mounted topper. Other optional attachments include onion windrower. (Amac)

standing, skill and adaptation to changes in conditions. A too-wide setting can pull out potatoes by extension of the roller springs; it is advisable to start with a narrow setting and only use a wide gap if essential. Adjustment of strips suspended over the web may be needed to assist contact between haulm and roller.

With expert use in spring of stone and clod windrowers, and harvesting by one of the best unmanned machines, crops can be taken from the field clean and very free from damage in reasonable lifting conditions.

Complete harvesters with hand sorting

The demand for avoidance of tuber damage during harvesting has led to the development of harvesters where the emphasis is on a high-quality product rather than a high work rate or minimum use of labour on the harvester. Features of such harvesters, which are normally single-row machines, may include:

- Offset share, low-angle web, and easy regulation of agitation independently of forward speed.

- Automatic regulation of share depth setting.

- Minimum drop at all transfer points within the harvester.

- Good ergonomic conditions for pickers, with canopy for protection from weather and dust.

- Rubber coating of steel components where appropriate.

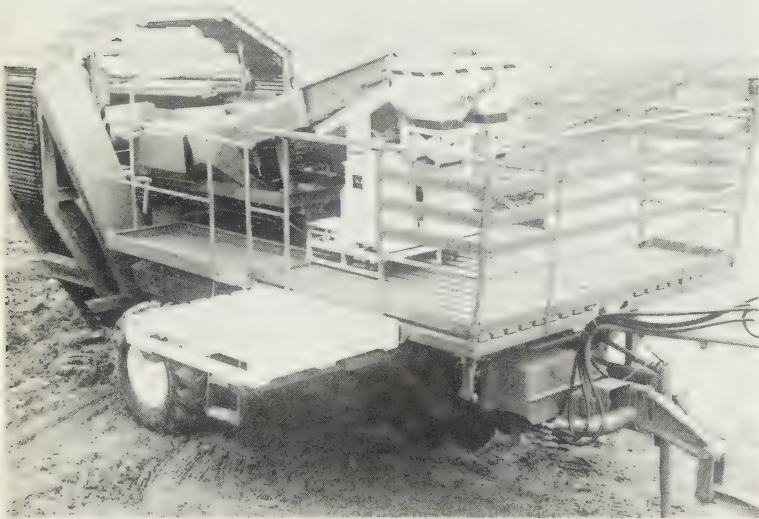


Fig. 15.8 Single-row harvester with hand sorting facility and a high-capacity automatic weighing and bagging-off unit, together with outriggers to carry pallets on either side of the machine. For high work rates, side loading bag elevator to pallets on trailer may be used. (Pearson/Grimme and Morray Eng.)

Easy regulation or automatic control of elevator delivery.

Some models provide good facilities for a large number of operators on the harvester; others aim to minimise the need for hand sorting by use of mechanical separators for stones and clods. Because of the low work rate, use of a bunker hopper on the harvester may be preferable to use of a continuous side-elevator delivery.

Clod separation

Before the mixture of potatoes, stones and clods passes to the automatic separation device it usually passes through a clod crusher consisting of a pair of rollers which have to be adjusted to break up large clods without damaging large potatoes.

Various types of clod separator are used. One consists of a transversely inclined studded belt which runs horizontally quite slowly, and others use a smooth belt that runs up an incline at a fairly high speed. In either case the round potatoes tend to roll down the incline and the

more angular clods and stones either stay on the slow-moving belt or are taken up the incline by the fast-moving one. The angle of inclination of the clod separator is easily adjustable to suit changes in conditions. Subsequently, pickers on the machine sort out the resulting mixtures, removing any potatoes from the rubbish conveyor and/or taking out rubbish from the potato conveyors before the crop is finally delivered to a trailer or to containers carried on the machine.

Stone separators

In some light stony soils the stones are round and smooth, and easily freed from the rest of the soil; but they roll like potatoes and cannot be separated by the usual types of clod separator. For such conditions some manufacturers offer a stone separator consisting essentially of a roller covered by soft nylon bristles. The stones tend to sink into the bristles while the 'lighter' potatoes do not.

Separation by X-ray sensor channels and high-speed pneumatic deflectors acting on a carefully regulated flow ribbon has become mainly confined to stationary machines which work at a store where they can be effectively protected and maintained.

Bagging and bag handling

Many farmers need a harvester that facilitates direct marketing of early or second-early crops. Equipment required includes a weigher specifically designed for the job, bag-closing equipment and pallet-handling equipment. The pallets may be designed for loading on the harvester, and for setting down by a hydraulically actuated platform without stopping the harvester. Such harvesters need a good flat working platform with the necessary safety rails and guards.

Transport and bulk handling

An important factor in any system of transport and bulk handling is avoidance of unnecessary crop damage. Potatoes at harvest time can be severely damaged by being dropped on to hard surfaces, or even on to one another at drop heights over about 457 mm (18 in). Studies by the Scottish A.E. Centre showed that in farming practice drop heights average 780 mm (31 in) at the beginning of loading and 480 mm (19 in) towards the

end. The least that is required of a harvester is a final delivery elevator with easy manual height control; but the best solution is automatic control. This is difficult to arrange with side delivery to vehicles running alongside the harvester, but easier if the crop is first collected in a bunker on the harvester.

‘Bunker’ hoppers on harvesters

With one-row harvesters where an attempt is made to remove all contaminants in the harvester, work rate is usually slow. Use of a bunker on the harvester can avoid losses on turns, reduce mechanical damage and save a man, tractor and trailer on transport. Two main types of emptying mechanism are employed: hydraulic tipping and use of a wide chain conveyor. Some machines are designed for emptying ‘on the move’, but with most mechanisms there is something to be said for stopping to ensure that no unnecessary crop damage or loss is caused during transfer.

Comparison of harvesting methods

A typical performance of a modern single-row harvester with three men working on the machine is 0.1 ha ($\frac{1}{4}$ acre)/hour. Total leavings usually range from 1250–1880 kg/ha (10 to 15 cwt/acre), but in good conditions leavings which would pass over a 41 mm ($1\frac{5}{8}$ in) riddle are only 625–1250 kg/ha (5–10 cwt/acre). A two-row harvester, working in good conditions with four or five men on the machine, can do about 1.2–1.4 ha (3–3 $\frac{1}{2}$ acres)/day, while an unmanned two-row machine can do 2 to 3 ha (5 to 7.5 acres) in 8 hours.

By comparison, a well-organised gang of 12–15 hand pickers can do up to 1 ha (2 $\frac{1}{2}$ acres) per day, and leave on average a total of about 2 $\frac{1}{2}$ tonne/ha (1 ton/acre).

Performance of a harvester varies considerably with soil type and condition, ideal conditions being a fairly dry, free-flowing soil, without clods or stones. Trials have shown a considerable advantage in work rates for 910 mm (36 in) row-widths compared with 760 mm (30 in). This is partly because wider spacing permits shallower cultivation in forming the ridge, and results in a lower proportion of clods. In an ADAS trial where four pickers worked on a one-row harvester, work rate was typically 20% higher for the wider rows.

An important factor in choice of harvesting method is avoidance of damage, which may make the potatoes immediately unsuitable for market, or cause subsequent losses in storage. The main sources of damage when using a harvester include cutting the tubers by a badly adjusted share, knocking them sharply by striking them with rapidly accelerating rods on cleaning mechanisms, shaking them with stones or hard angular clods and dropping them on to hard surfaces. Both harvesters and subsequent handling methods are being improved, and the best machines and methods can achieve a quality of work at least as good as that usual with hand picking. There is no doubt that the use of harvesters will continue to extend.

Haulm destroyers

The success of the best haulm extraction rollers when properly set makes use of a haulm pulveriser unnecessary and inadvisable in main crops. A chemical haulm destroyer used about 10 days before lifting does all that is helpful. Use of a pulveriser may, however, be necessary when lifting early crops with equipment not of recent design.

The most widely used type of haulm pulveriser employs beaters attached to a horizontal miller shaft and usually contoured to match the ridges. The rotating beaters may consist of hoe blades, steel hammers or rubber hammers. They act mainly by virtue of their peripheral speed, which is often in the region of 40.7–61 m/s (8000–12000 ft/min). Haulm pulverisers require a considerable amount of power where the tops are long and tough, a light-medium tractor being capable of doing only 2–3 rows at a moderate speed. Machines not designed primarily for haulm destruction which can sometimes be used to good effect include horizontal rotary slashers and flail forage harvesters. The latter are particularly effective where the wheels and height of work can be adjusted to suit the crop, since the suction lifts haulm lying between the rows. Thorough pulverisation followed by a delay of about 10 days before the crop is harvested may be advisable where haulm is heavily infested with blight.

Equipment for potato storage

Indoor storage is everywhere superseding storage in clamps, and this trend is likely to continue. The only

disadvantages are the cost of the store and the fact that a central store often necessitates a fairly long haul. Storage in bulk is generally favoured, and where the store is purpose-built it pays to store to a depth of about 3 m (10 ft) and to provide for forced ventilation. Piling potatoes to a depth of 3 m (10 ft) usually calls for the use of an endless-chain or belt elevator, fitted with a large receiving hopper and with means of separating out loose soil from the crop. Soil separation is necessary because there is a tendency for potatoes to heat if soil cones which form beneath the elevator outlet interfere with ventilation of the heap. Star cleaners are often used on silts and heavy loams for soil extraction between the receiving hopper and elevator when filling stores, and also on some two-

row harvesters between the chain web(s) and delivery elevator. The rubber stars with backward-curved points are mounted on a series of parallel revolving shafts and arranged so that the tips of the stars pass between gaps in the adjacent rows. The crop is propelled gently on the tips of the stars, while soil, clods, trash and small stones are helped through the pre-set gaps.

A method of filling and emptying the store that is expensive, but has many technical advantages is use of a fixed-belt conveyor along one side, and a cross conveyor mounted on a bridge which spans the store. The bridge is carried on rails, and can be moved along the store as filling proceeds. Such equipment facilitates use of fixed pre-cleaning equipment during loading, and fixed sorting, packing and weighing equipment when the store is emptied by reversing the conveyors.

Root crops storage in boxes

The practicality of storing root crops such as potatoes and onions in boxes has been advanced by improved knowledge from research on the environmental conditions required (see Chapter 23) and also by the ability of modern handling equipment to transport and stack filled boxes safely to considerable heights in purpose-designed buildings.

Handling the crops into boxes needs to be carried out without bruising in order to preserve good keeping quality, and accepted aims include avoidance or limitation of dropping the crop on to hard surfaces during harvesting, cleaning and handling work including box filling.

A box filler specially developed for potatoes and onions is shown in Fig. 15.10(b). Filling development was greatly advanced by a system which provides for automatic use of a reversible horizontal filling conveyor via a Programmable Logic Controller (PLC) with a number of sensors operating in conjunction with a system of raising and tilting the clamped box to a position where the inside of the box is open to entry by the adjacent end of the reversible conveyor. The conveyor first drops the crop about 50 mm (2 in) on to the inside end of the box, and the crop rolls down the gentle slope to begin accumulating in the 90° angle between the lower end and the nearly vertical bottom of the box. From that point filling is controlled by proximity sensors which cause the box being filled to be progressively lowered until the bottom is horizontal, the top layer is completed and the conveyor is

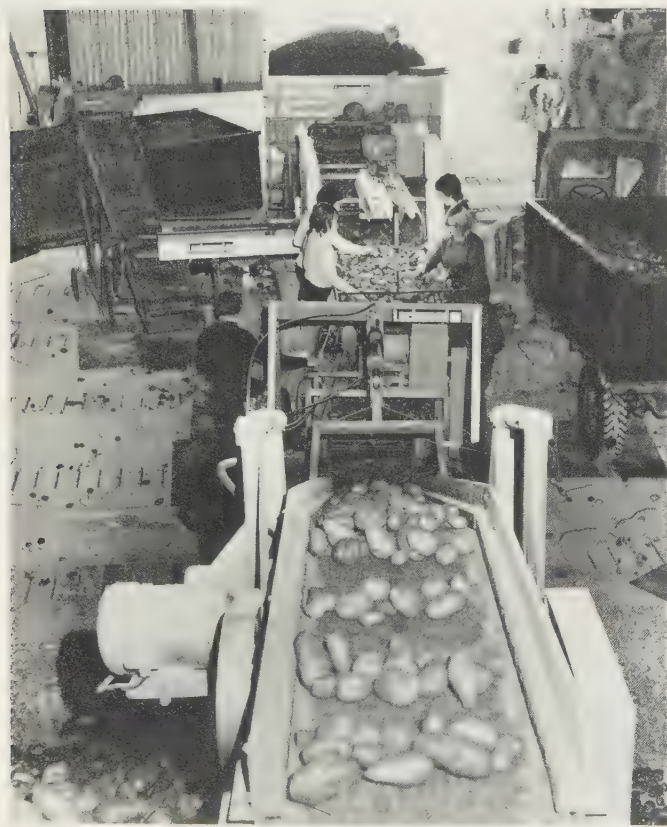


Fig 15.9 Loading potatoes into bulk store. The self-unloading trailer feeds a high-speed grader which removes 'chats', rejects, stones and clods. The ware passes to a hydraulically controlled store-loading elevator. (Lockwood)

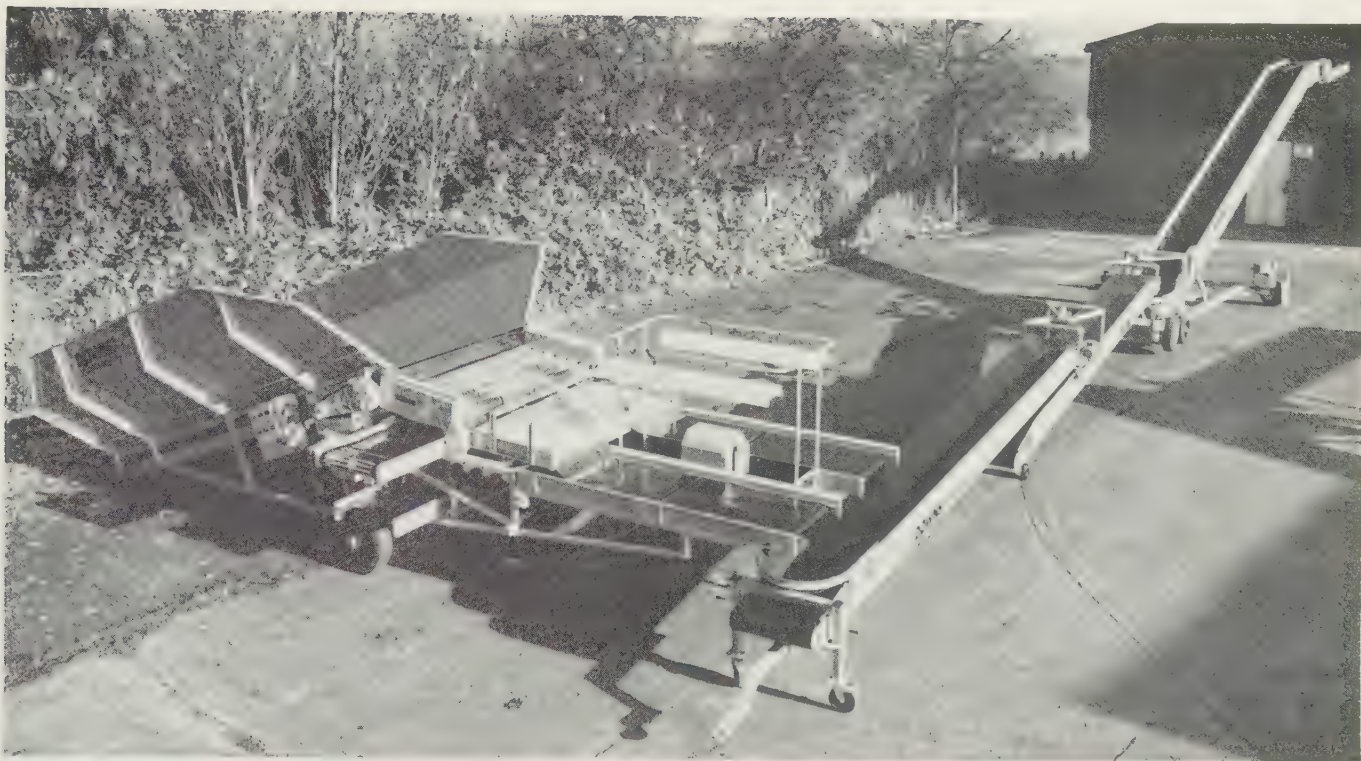
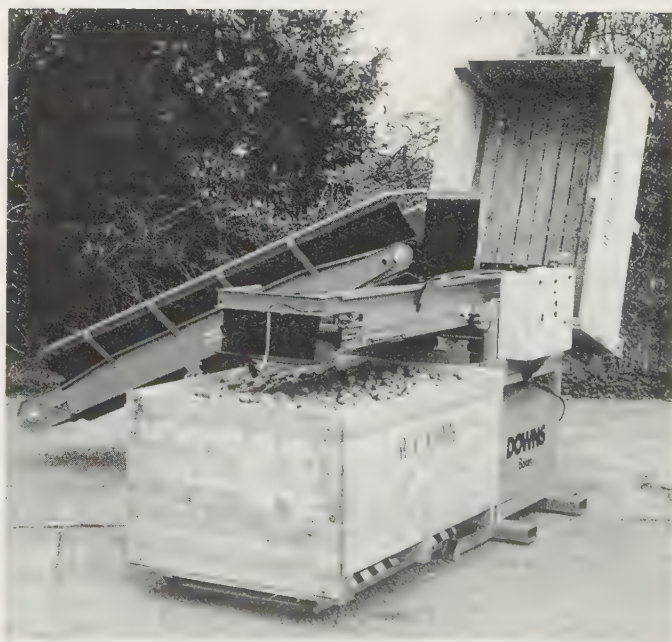


Fig. 15.10 (a) Handling into store from tipping trailers. Bulk receiving hopper with 1.8 m (6 ft) belt has 3.3 m (11 ft) wide trailer entry and six-row cleaner (choice of type) at delivery end. Hopper sides fold to 2.5 m wide for transport. Cleaner gaps are infinitely variable from 0 to 50 mm, so can be used for removal of chats or small seed. A chats conveyor with 25 mm gaps can be mounted at right angles to flow, beneath the cleaner; and a reversible soil conveyor can run below it. Wheel controls for hopper conveyor speed, cleaner speed and cleaner gaps are shown located near the ware sorting belts. Illustration shows use of telescoping conveyor which can connect at any angle, and a swinging elevator with electric wheel drive and hydraulic slewing. (*Downs*)

Fig. 15.10(b) Automatic continuous-flow box filler for potatoes and similar easily damaged vegetable crops. Crop flow is alternately to right and left of the inclined feed conveyor, and a Programmable Logic Controller is incorporated to ensure safe and efficient operation. At beginning of filling the empty box at far end the box is tipped as seen: when flow begins, reversible conveyor moves forward into box and drops crop gently on middle of the slightly sloping box end. As the box fills it is gradually returned to same relative position as the filled box in foreground. Rate of work depends partly on how quickly full boxes can be replaced by empty ones. (*Downs continuous-flow Boxer*)



automatically withdrawn for use on the other side of the machine. By this time any box which had already been filled should have been removed by mobile handling equipment and replaced by an empty box. Throughputs of up to 60 tons/h are possible, but achievement is partly dependent on the rate at which the boxes can be supplied and removed.

Potato sorters

The potato marketing regulations have made it necessary for all potato growers to produce properly cleaned and graded samples. Simple types of mechanical sorters usually have an intake section to get rid of loose soil, a grading section which as a minimum separates unmarketable 'chats', and a conveyor where diseased or damaged tubers or stones, etc. may be removed by hand from the 'ware'. Machines with reciprocating riddles, a rotary screen, adjustably-spaced rollers, etc. were once widely used and may be satisfactory for small enterprises; but for most farms where potatoes are important, endless screens with rectangular openings are now a common choice. Reasons include ease of control of throughput by variable-speed motors, easy change of screen size and degree of agitation of the web, and gentleness of handling where the designer takes care to minimise height of drop when the crop is moved from one section to another. The screens may be rubber-covered; and agitation is provided by

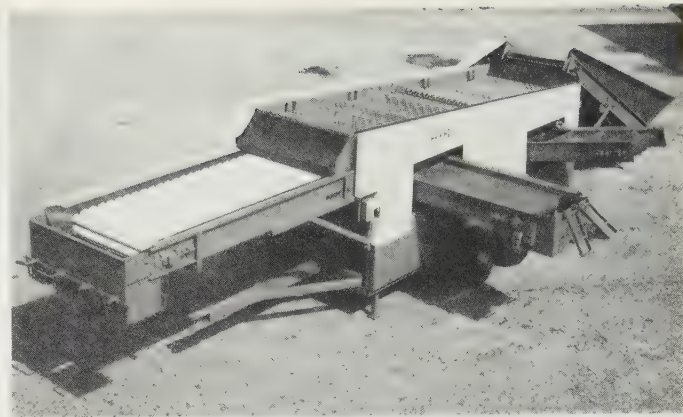


Fig. 15.12 Mobile double-screen potato grader with small loading hopper, soil conveyor, chats conveyor, and bagging attachments for ware and chats. (Cooch)

eccentric idlers. Modular designs provide for linking together cleaning sections with one or more grading section(s) and finally an endless belt or roller picking table.

In a favoured double-screen arrangement there is usually a short conveyor to remove soil and chats from beneath the first screen and a longer conveyor to permit inspection and sorting of the seed-size yield from beneath the second screen. Chutes from the sorting table to individual cross conveyors (Fig. 15.13) are a worthwhile provision.

Specialist marketing equipment suitable for large-scale enterprises includes rotating spool modules for purposes such as separating oversize tubers, and dry brushes to improve the appearance of mature crops marketed after storage.

The spool type of sorter has a series of rubber-covered rollers each with a diameter which varies regularly along its length, to form a number of apertures approximately circular in shape. These handle potatoes with less bruising than the older types, but are comparatively expensive. The spools have a pronounced cleaning effect on dry potatoes but may brush off the skins of newly dug first earlies. By choice of spool pattern and size it is possible to produce several size grades between about 29 and 63 mm ($1\frac{1}{8}$ and $2\frac{1}{2}$ in).

Steadily increasing use is made of a simple device for providing stepless variation in speed of the mechanisms over a wide range. This allows the speed to be easily suited to the sample.

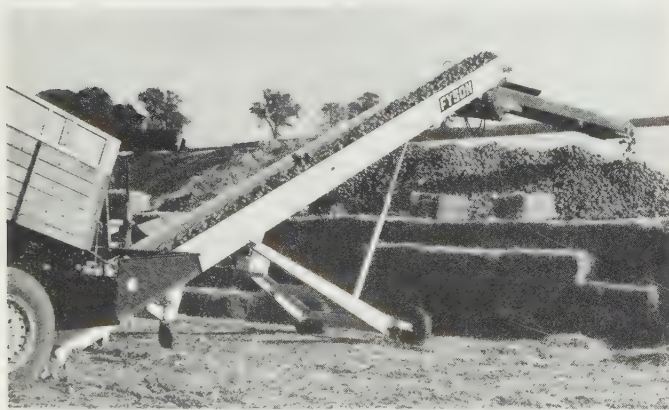


Fig. 15.11 Rubber-belt store-loading elevator using auto-swing extension to fill large outdoor clamp. (Fyson 'Elevator II Auto-Swinger')

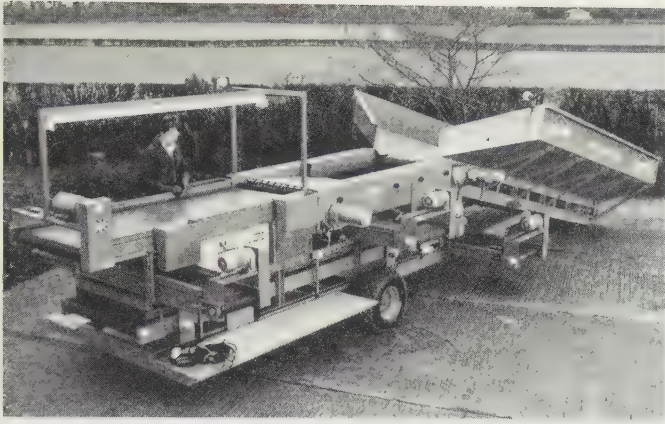


Fig. 15.13 Modular design 'in-line' grader with minimal drops throughout the system. Photo shows 36 in wide unit with star cleaner module between bulk hopper and grader; and location of soil conveyor, chutes conveyor, and chutes to make sorting easy. Controls are mounted on a single panel and provide speed variation in all crop conveyors. A split grade of ware can be obtained by adding a second grader module at the end of the sorting table. (*Cranford*)

Electronic sorting

Automatic separation of stones and clods can be reliably effected by stationary X-ray sorters housed in good operating conditions as the potato store. Such equipment can be used in conjunction with unmanned harvesters both when filling and unloading stores.

Newer uses of electronic aids include length grading by 'Teleslector' (e.g. Lockwood). The Teleslector employs a TV camera to view the produce on a specially designed roller conveyor.

Potato brushers

Ware potato samples can often be profitably improved by use of a brushing machine to remove dry soil; the machine is usually located between the end of the grading line and weighing machinery. A typical machine consists of an enclosed conveyor made up of driven rollers carrying closely-spaced bristles. Soil removed falls between the rollers. The considerable amount of dust created needs to be drawn from the machine by an adequate air-stream

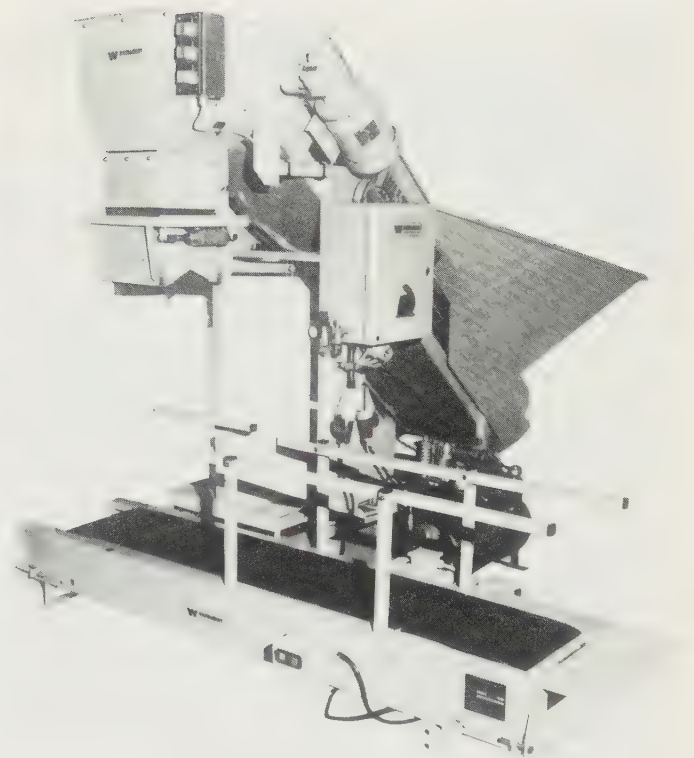


Fig. 15.14 Fully automatic bagging and weighing unit for potatoes, carrots, onions, etc., packed in paper, hessian or plastic bags of 10, 20 or 50 kg. Capable of 230 bags/hr throughput. (*W. J. Morray*)

and delivered to a suitable collector outside the working area. Chain drives and bearings need to be well protected from the soil. One type of brusher has a line of height-adjustable brushes above the crop in addition to the lower conveying line; lowering the top line increases length and severity of the treatment.

Potato washing is briefly considered under vegetable washers in Chapter 16.

Vehicle loading aids

Research and development work carried out over many years at the Scottish Centre of Agricultural Engineering on bruising damage to potatoes and similar vegetable crops, caused by unnecessary or excessively long drops

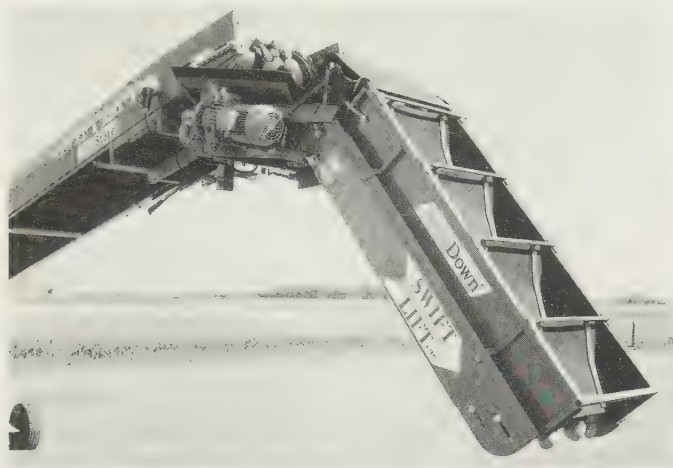


Fig. 15.15 Swift-lift 'Safedown' Damage Reduction Elevator Head Extension.

The automatic swinging head extension illustrated is designed for gentle handling of bulk potatoes and similar vegetable crops when loading them into storage boxes, direct into bulk store, or into road transport for delivery to buyers. The crop is carried to the extension on a 600 mm (24 in) wide endless rubber belt to the 'Safedown' extension of swan-neck type when fitted. The extension has a 1.5 m (5 ft) reach, and can be angled on a 62° swing for spreading the load into boxes or bulk transport vehicles. Speed of the belt can be varied from 13 to 69 m/min. The crop is carried down the extension between a cleated rubber belt and curved floating overlays of rubber fingers which restrain each tuber until the end of the swinging extension conveyor is reached. (*Swift-Lift Elevators*)

within machines and by machines engaged on practical loading operations have shown that not all of the damage is incurable: both progressive farmers and manufacturers have become well aware of the machine design improvements that can be and have been made already, and that this subject still needs to be given priority when any new handling or storage installation is being designed.

Where handling throughputs are large, and the conditions of work are always approximately the same, good use can now be made of proximity sensors which, with the help of a simple microprocessor, can make good use of sensors of the type nicknamed 'Noddy' for ensuring that loading elevators do not needlessly drop tender vegetables long distances on to hard surfaces or on one another.

For mobile loading-out elevators on farms, where transport vehicles vary widely, and a responsible member of the farm staff almost always needs to be present, simple mechanical devices like the loading elevator extension shown in Fig. 15.15 can provide a valuable service with only the additional need to check that a normal safe electricity supply as now generally found on progressive farms is available.

Sugar beet harvesting

Harvesting equipment has undergone rapid development in many different directions. There are three basic operations to be carried out: (a) topping, (b) lifting and cleaning, and (c) loading. In addition, it may be necessary to windrow or to load the tops. Some harvesters top, lift, clean and load a single row. This can be efficient with a one-man tanker machine, but tends to be inefficient where side-loading is carried out. With multi-row harvesters the rate of work can be high, and side-loading can work well.

Two-row tanker and three-row side-loading systems suit many users.

Five- or six-row three-stage systems were formerly widely used in France, but have many disadvantages and



Fig. 15.16 Two-row self-propelled tanker sugar beet harvester based on Case demountable skid unit. Front-mounted hydraulic drive pre-toppers, scalper toppers and wheel lifters are followed by cleaning by rotary 'Cyclone' and Continental web mechanisms. (*Standen 'Tornado'*)



Fig. 15.17 Six-row self-propelled sugar beet harvester powered by 200 kW (268 hp) engine with four-wheel drive and four-wheel steer hydrostatic drive to equal-sized wheels. Rear wheel drive only is available for roadwork, and automatic differential lock is an option in the low gear range. Tight headland turns are provided by a manually operated 'steer assist' lever operating on the rear wheels. Ability to take mechanical drive power from both ends of the engine assists a logical distribution of the main components with the engine and its tanks well to the rear where direct mechanical power can be used for driving cleaners and elevators. Electronic sensors and microprocessor provide distance, area and forward speed information. In-cab noise level is lower and seat better than normal tractor regulation requirements. (Standen 'Challenger' SP6)

have been widely replaced by multi-row self-propelled harvesters.

The Matrot 31E is powered by an air-cooled engine of 175 kW (227 DIN hp) via Sauer hydrostatic transmission to a front axle with limited slip differential, which is rigidly fastened to the chassis and has its two 12.4 × 36



Fig. 15.18 Matrot 31E self-propelled six-row electronic-control sugar beet harvester with holding tank and direct side-delivery beet loading elevator. (Matrot UK Ltd)

wheels steered by Orbitrol system. The rear axle has two 20.8×38 wheels on an axle with a separate hydrostatic drive and steering system on an articulating rear chassis. Steering of the rear wheels, e.g. on headland turns, is controlled by two mushroom shaped foot pedals, for left or right rear-wheel turns, which return the rear wheels to straight ahead when no pressure is exerted on either pedal. Two-stage topping is by hooded large diameter flail rotor, with high speed auger in a trough for side delivery of the leaves. Individual row scalpers are used for the next stage of topping. There is a choice of lifting options, including discs, auto-guided shares and Oppel wheels.

'Joystick' centralised electronic controls cover items such as front wheel alignment, delivery elevator angle and drive, emptying holding tank, and speed of spiral cleaning turbines and delivery elevator. Height of flail topper, scalpers and lifter depth settings are all automatically regulated by microprocessor using sensors attached to two carefully designed feeler bars.

Topping mechanisms

Most topping machines, topper-loaders and complete harvesters top the unlifted beet and rely on a feeler

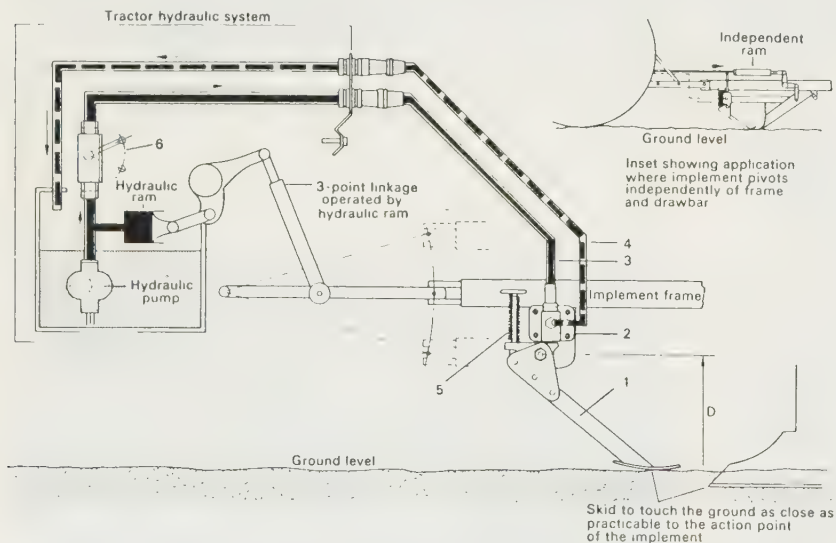


Fig. 15.19(a) Automatic hydraulic depth control for root harvesting equipment. (Salmon)

Feeler skid 1 operates restrictor valve 2 which regulates oil flow to internal tractor ram. As the implement sinks, valve restricts flow from 3 to 4, and the harvester frame is raised, and vice versa.

wheel, track or sledge of some kind, which is designed to run over the crowns of the beet and determine the setting of the knife or knives which cut off the top. Manufacturers aim to make a light topping unit, which will not push the roots over as it rides on the crowns, and which will adjust itself rapidly when passing from a large root to a small one and vice versa. Where a simple topping knife is used it must be thin and sharp, and must be set at an acute angle to the row, in order to minimise fracturing of the roots before cutting is completed. The knife is usually directly attached to the spring-loaded subframe which carries the feeler device, so the thickness of the crown removed is constant provided that the feeler mechanism bites firmly into the crowns. The feeler mechanism must run true along the centre of the row of beet, and there must be just enough pressure on it to ensure that it gets down to the crown. The use of flails or pre-toppers running ahead of the feeler wheel makes it easier for the feeler to adjust the topping knives effectively. The feeler wheel is slightly overdriven to hold the beet against the topping knife, and the knife must be set according to the



Fig. 15.19(b) Hydraulic-drive 'skew-bar' topper available as option on single-row trailed harvester. (Standen 'Rapide' Mk 3A)

average size of the beet, so that the cut begins when the feeler wheel is well on top of the crown of the beet. Success of the harvesting operation depends very largely on careful setting of the topper, and on attention to such details as keeping the knife really sharp. It pays to have spare knives available so that machine-sharpened ones can be quickly fitted.

The 'skew-bar' developed by Silsoe Research Institute and fairly widely available as an option is best used in conjunction with a vertical-axis multi-knife 'turbo' pre-topper which is front-mounted on the power unit, hydraulically driven, and removes the majority of the green leaves. The hydraulically driven skew-bar cylinder fitted with a series of curved blades makes a rounded cut leaving more of the centre of the crown intact than a straight knife cut; a yield increase is claimed. The action of the topper tends to pull the tops of loose roots towards the following 'Oppel' type lifting wheels and is claimed to result in fewer roots left in the field.

In one type of harvester (e.g. Armer and Scott Urschell) the beet are lifted whole and topping is done in the harvester (see p. 253).

When separate toppers are used the beet must not be topped too far ahead of the lifter, otherwise serious loss of sugar from the roots is likely. If beets are left in the ground only a few days after topping, some small loss may be found. If they are left for more than a fortnight the loss of sugar is likely to be appreciable.

Where topping is carried out as a separate multi-row operation and tops are to be collected for feeding, it is possible to use a trailed machine (e.g. three-row) that collects the tops, e.g. by chain web and auger, and delivers them by blower direct to a trailer. Such machines normally work immediately ahead of a lifter-cleaner-loader. Where the tops are not to be collected, lighter tractor-mounted 3-row machines can be used. These may consist of steel flails and an auger to remove the leaves and deliver them on to the already harvested land. On three-row complete harvesters (e.g. Standen 'Spectrum'), three-row vertical-axis knives with scrolls ('Turbo' pre-toppers) throw the tops to one side on to the harvested land. Topping knives of a simple 'scalper' type can work effectively after the leaves are removed.

Lifting and cleaning machines

Lifting and cleaning machines may deal with one or more

rows at a time, may be trailed or tractor-mounted and may deliver the beet in windrows parallel to the work or at right angles to it.

With all types of lifter the following general principles of operation apply: (a) the machine must be accurately guided either by skids or by being steered, so that the line of beet is centrally between the lifting points or shares; (b) the lifting prongs or shares should be set to 'pull' the beet, so far as this is possible, without breaking off too much of the tap root. The less earth that is lifted with the beet the easier the cleaning and carting off; (c) cleaning devices should be adjusted to give adequate cleaning without doing serious damage to the roots. Where necessary, forward speed must be reduced to give more cleaning.

One of the most widely used lifting devices, used mainly on complete harvesters, consists of a pair of inclined lifting wheels (called 'Oppel'), which pull the roots and can result in low dirt tares.

With all the machines that leave beet in windrows, care must be taken not to have a big acreage of beet exposed in frosty weather. A frost that will do no harm to beet stored in a big clamp will render useless for processing beet that lies uncovered in a thin windrow.

Complete harvesters

Where tops need to be saved for stock feeding the belt-lifting complete harvesters which top the crop in the machine have a head start on competitors. The improvements made in these harvesters by all-hydraulic drives are referred to on pages 252–6. The current size range makes it easy to provide for most sizes of livestock enterprise, and the machines are designed with the benefit of past successful experience in this particular field. Tankers provide flexibility in operation, with their ability to work independently of other transport equipment if necessary. With multi-row tankers a minimum area of the field has its soil structure damaged by vehicle wheelings. The range of S-P tankers runs from relatively inexpensive one-row harvesters powered by a tractor unit that can be lifted off and used as a conventional tractor at other times of year, up to purpose-designed multi-row harvesters with hydraulic and/or variomatic drive to the main components. The larger S-P tankers are inevitably expensive and usually single-purpose. With six-row S-P side-loading harvesters transport is a major problem.



Fig. 15.20 Three-row side-loading trailed sugar beet harvester with open construction allowing wide range of options, as follows:

Size: Can also be four-row,

Topping: skew-bar or heavy-duty scalpels,

Lifting: Oppel wheels,

Basic cleaning: double continental web,

Trash removal: reverse-running extractor elevator or barrel type

General: holding and loading. Rear cross conveyor with elevator drive stopped can hold approximately $\frac{1}{4}$ tonne or 50 m run,

Elevator: Adjustable angle and dipper end, whole hinged and folded inwards for road travel,

Preliminary leaf removal: four-rotor turbo leaf cutter height adjustably mounted on front of tractor. Drive by front pto or hydraulic, using oil from harvester supply.

Automatic depth regulation and row-seeking attachments – optional.

Hillside steering axle which also assists headland turns – optional. (*Standen 'Spectrum'*)

Provision of a small holding tank of about 3 m³ capacity can increase daily output by about 10%.

The cleaning mechanisms employed in complete harvesters include a rotating spinner in a stationary cage, various kinds of rotating cages, elevator chains running on agitators and revolving knockers which shake and rub the roots.

On harvesters that rely for cleaning mainly on chain and rod-link conveyors, provision is usually made for extra rubbing by passing the roots between two webs driven at different speeds. Adjustment is provided to

widen the speed differential where extra rubbing is needed.

Harvesters that top the beet after lifting have a pair of rubber-faced elevator chains to grasp the beet tops at the same time as the roots are loosened by a small share running beneath the row. The elevator chains run backwards and upwards, and are geared to travel backwards at approximately the same speed as the machine travels forward. This ensures that the beet are pulled vertically out of the ground by means of their tops, which are firmly gripped between the elevator chains. The pulling of the beet is one of the strong points of this type of machine, for much of the soil is stripped off in the process.

At the top of the elevator the beet, still carried by their tops, are delivered to the topping knives, which consist of two rotating discs with serrated edges.

Developments which are certain to become of increasing importance are automatic controls of various kinds. One already applied to British harvesters is automatic control of share depth. Ordinary depth-control wheels can be quite effective in firm soil conditions, but are unreliable on soft land. The automatic control unit has a light sensing arm which operates a hydraulic valve control and so raises or lowers the hydraulic lift. This can result in a more uniform working depth.

Some harvesters have automatic steering. Guide-type row-finders act as sensors and are connected to a valve which directs oil flow from the tractor to a double-acting hydraulic ram. This moves the machine laterally relative to the tractor hitch. There is a manual over-ride to allow the driver to guide the machine into the crop at the headland.

Sugar beet cleaner-loaders

When beet is carted from the fields and dumped in heaps by the roadside, loading into lorries for transport to the factory is usually carried out by an engine-driven elevator, the hopper of which is filled by a tractor loader. There are, however, many types of equipment for both loading and elevating.

A good cleaner-loader needs to be equipped with a fairly large, sturdy hopper suitable for receiving the beet from a hydraulic front-loader or special-purpose loading vehicle. It pays to clamp the beet on a hard surface so



Fig. 15.21 The belt-lift, in-machine-topping system of harvesting sugar beet has been in practical use since Scott-Viner machines were first used in USA in the late 1930s. Modern tractor developments, with ease of providing 75 kW to power the middle-of-range two-row Beaver Super HD illustrated, and particularly to provide the infinitely variable hydraulic drive speeds for the lifting belts and improved cleaning carousels, together with the low-tare and low yield loss of the modern in-machine topping system and 3 m high delivery of crop to the transport trailer, make the current line worth seeing. (*Armer-Salmon Beaver HD*)

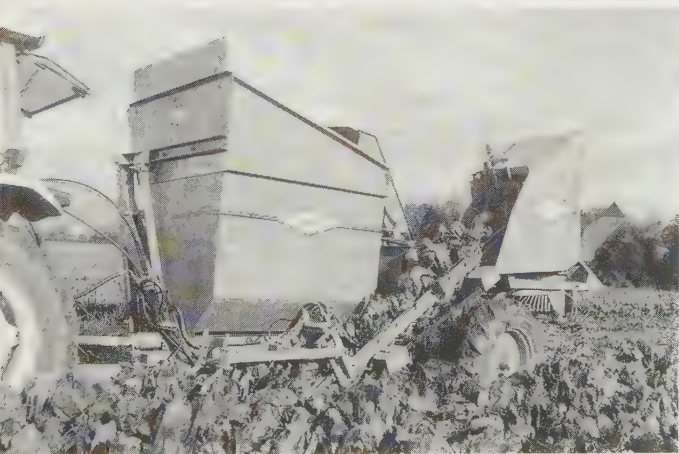


Fig. 15.22 The one-row belt-lift in-machine topping harvester has full hydraulic drive and is shown with the relevant sheet metal chute at the rear arranged for top saving by windrowing. Part of the improved variable-speed cleaner carousel can be seen below the tops delivery hood. (*Armer-Salmon Cheeta HD*)



Fig. 15.23 Tractor having reverse console used front-to-rear with six-row beet topper-lifter and windrow pick-up loader. (*Kleine on M-B-trac*)

that the vehicle operating the loader can easily manoeuvre, and in order to avoid picking up an unnecessarily large amount of soil with the roots. The loader should preferably use a well designed open-grille type of bucket which shakes out loose soil during lifting.

When the roots have been clamped in a very dirty condition, large amounts of soil are rapidly removed by a cleaner-loader, and it is important to have plenty of room for the soil to accumulate without interfering with the working of the machine, and also to be able to clear the soil easily from beneath the machine. It is an advantage to be able to move the machine easily (see Fig. 15.26).

Another type of loader which is suitable for loading either direct into trucks or into the hopper of a cleaner-loader is the slewing boom type of hydraulic grab. This is less dependent than a front-loader on good ground conditions, since the tractor can remain stationary for long periods. One method of use is to mount the cleaner-loader on the front of a tractor and to fill the hopper by means of a slewing loader with a wide slew angle, preferably 360°. In good conditions a loader driven by a 0.9 l/s (12 gal/min) independent hydraulic power unit is capable of loading up to 1 ton/min.

Early harvesting and carting to the roadside has the advantage that the crop comes up cleaner and is more easily carted from the fields, while ploughing for subsequent crops may be done in better season.



Fig. 15.24 A four-wheel-drive telescopic-boom rigid-chassis loader with grille type root bucket and pick-up hitch for trailers tidying up sugar beet clamp. (JBC)

Turnip harvesters

Harvesting swedes and turnips is a relatively simple operation compared with sugar beet harvesting, and the main reason why progress in the development of harvesters for this purpose has been relatively slow is that many crops are fed off by sheep where they grow. Nevertheless, now that the spring work on such crops can be fully mechanised there are few difficulties in growing and harvesting this crop.

Some so-called harvesters merely consist of an arrangement of knives for topping and tailing the roots, which are then pushed aside into a windrow. Other machines collect the roots and load them into a trailer running alongside.

One-row harvesters that top the row being lifted include a trailed machine with hydraulically tipped cage hopper of about 1 tonne capacity – a feature that helps to avoid having to wait for transport (e.g. Thomas). Other types are side-loading and linkage-mounted, and may top the row one ahead of that being lifted (e.g. Blair; Reekie). A typical topping unit consists of a multi-bladed rotor that floats on and is centralised by tapering skids. A driven disc may be used for root cutting, and various kinds of

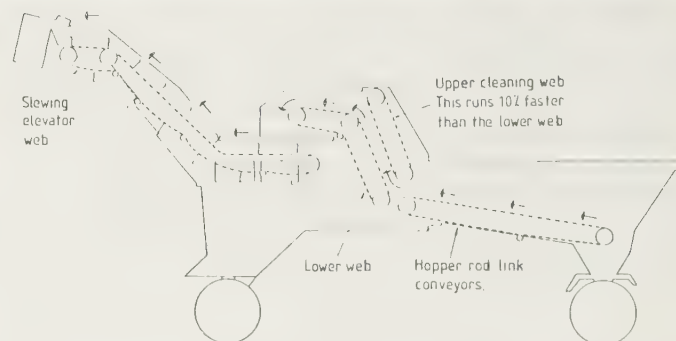


Fig. 15.25 High-speed sugar beet cleaner-loader (up to 4 tonnes/min) with 180° power slewed delivery elevator shown operating 90° to right of cleaning web. Diagram shows arrangement of conveyors and the dual web cleaning system. Bow-frame axle at the delivery end enables machine to be drawn forward over soil deposits. This 'top-of-range' machine (Euro-240 S) powered by 45 hp air-cooled diesel engine has 12 V electric start; hydrostatic drives to conveyors provide variable speed and built-in overload protection. Simpler low-power machines are suited to individual small and medium-scale enterprises. (CTM)

rotors and endless chain mechanisms are used to transfer, clean and load the roots (Fig. 15.26).

Carrot and other root vegetable harvesters

The traditional method of carrot harvesting by hand was to pull the roots, sometimes after loosening by hand



Fig. 15.26 One-row side-loading tractor mounted harvester for turnips, swedes, mangolds and other similar root crops. Tops are cut and swept to left side, and concave scalloped disc lifts the same row. Inclined wheel delivers roots to foot of endless chain elevator. (Blair 'Boswell')

fork; wring off the tops, and sort into grades as lifting proceeded. Such methods have been superseded by use of a wide variety of multi-purpose root vegetable harvesters and specialised carrot harvesters. Success in mechanical harvesting requires careful planning of growing methods to suit soils; season of lifting; type(s) of harvester to be used, and mechanised cleaning and grading.

One type of harvester uses a share and elevator web little different from that normally employed for potatoes. The harvester delivers the crop into a trailer running alongside, or to a bagging platform on the machine. There may be several operators on the machine to sort out rubbish. The chain web typically has a pitch of 33 mm ($1\frac{5}{16}$ in) for market carrots; a similar web with rubber covering may be used for canning. Direct bagging on the harvester cannot usually give a first class sample, and a more satisfactory method of operation is to transport the crop in bulk to a stationary sorting and washing machine, where much better market samples can be ensured.

A second type of harvester (e.g. Armer and FMC)

employs a gripping-belt lifting system basically similar to that used on the Armer and Scott-Urschell sugar beet harvesters. Shares loosen the crop according to need,



Fig. 15.27 Two-row self-propelled top-pulling carrot harvester with side loading. (Shelbourne Reynolds)

and any necessary topping is carried out in the machine. The main advantage of the gripping-belt lifting system is ability to lift tender crops with a minimum of damage, and almost free from stones even when crops are grown on very stony land. Limitations of this type are ineffectiveness when tops have died down, and the need to keep the crop-band narrow. Provision on a single machine of interchangeable primary lifting and elevating mechanisms makes it possible to get the best from both types of mechanism. The gripping-belt is used for lifting until the tops are no longer strong enough, and the share-and-elevator mechanism is substituted for the late-sown crops. To get the best from such a combination it is necessary to drill to suit the harvesting mechanism that will be employed. The main root vegetables mechanically harvested are carrots, parsnips and beetroot.

Two-row self-propelled harvesters with the same type of gripping belt lifting mechanisms can achieve high work

rates and a high standard of topping in carrots (e.g. Shelbourne Reynolds).

A similar specialised self-propelled vegetable harvester (FMC) is powered by a 100 hp air-cooled engine and fully hydrostatic transmission providing field speeds up to 12.5 km/h and 25 km/h on the road.

Hydraulic motors are used to reduce long chain drive problems. Carrot and similar tops are squeezed off by a well-proved rotary bar system; and a reverse drive to the lifting belts minimizes blockage difficulties. Season of use is limited as with all 'top-lifting' mechanisms. With share-lifting machines row and bed arrangements other than single narrow rows can be used with advantage. These include double, triple and wide-band rows, and also, on suitable light soils, a bed system consisting of up to 12 rows spaced 100 mm (4 in) apart. The bed system is ideal for uniform growth and high yield, but it requires the use of specialised share type harvesters, preceded by a precise

topping operation. Adapted flail forage harvesters were formerly used for the topping, but a specialised combined flail-and-brush machine (e.g. Reed & Upton) has been developed to achieve more perfect results. Uniform topping requires very good seedbed preparation and drilling, so that the soil surface is level and the crop uniform in growth.

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Horticultural Machinery

Special power units and cultivation implements

On open land, most kinds of market-garden crop can be successfully grown by using a light-weight medium-powered four-wheeled tractor equipped with hydraulic lift, a good range of standard agricultural equipment and wheels which can be set out to a maximum track width of over 1.8 m (6 ft). The crops may be drilled or planted in beds, with row-widths down to 100 mm (4 in), provided that wider paths are left for the tractor wheels at the outsides of each bed. Thus, each bed may comprise, according to the nature of the crop grown, six rows 270 mm (11 in) apart, five rows 350 mm (14 in) apart and so on, with pathways of 500–730 mm (20–25 in) between beds. For work on such crops, self-propelled tool-bars for drilling, hoeing and spraying are helpful, but by no means essential. Carrots may be grown in beds having rows only 100 mm (4 in) apart, since weeds in this crop can be controlled entirely by spraying.

The need for special types of power units and/or cultivation implements arises when it is necessary to work between fruit trees or in hopyards, where the planting distance has already been decided and the equipment has to conform to it. Even here, there is often a case for planning planting distances to suit machinery, when the opportunity for replanting occurs.

Narrow rows of fruit and hops sometimes necessitate the use of extremely narrow tractors, with overall widths of about 1.2 m (4 ft). Such tractors require specially adapted mounted equipment, and use, among other implements, types of plough which are designed for ploughing up to or away from both sides of rows of hops or fruit. One type of hop plough suitable for very narrow work turns two furrows to the right and two to the left simultaneously, covering all the ploughable land in one bout. Cut-down tined implements and disc harrows are also used.

Another type of special-purpose implement is needed for rather wider rows, where it is desired to work as close to one side as possible. For this work, offset ploughs which will work up to the outside of the tractor wheel mark can be obtained.

Compact tractors

Leading agricultural tractor manufacturers now almost invariably offer an attractive range of 'compact' four-wheeled tractors with an array of rotary mowers, front loader, rear rotary tiller and other equipment designed for use in large gardens and small public recreation areas. Domestic specialist ride-on mowers are not considered here. The engine power ranges of individual manufac-



Fig. 16.1 Low-powered 'compact' tractors can be useful for many purposes in commercial horticulture. The axle design (see Fig. 2.45) can provide both four-wheel-drive and good clearance. The three-cylinder model shown operating a transplanter develops up to 27.4 DIN hp (20.5 kW). (*Ford New Holland*)



Fig. 16.2 The 17 hp 235, smallest of a range of three models up to 28 hp, is shown with four-wheel-drive and mid-mounted mower suited to well kept lawns or fairways. A wide front-mounted mower of same general type can be used. (Case International)

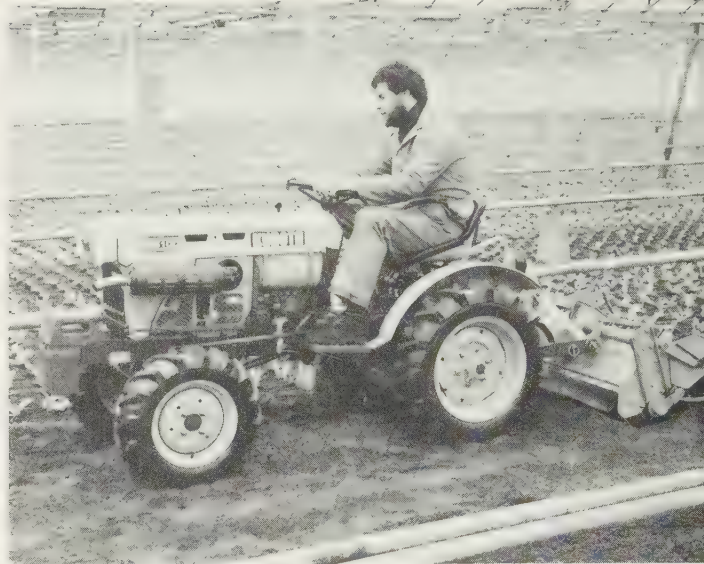


Fig. 16.3 Above: Compact four-wheel tractor with rotary cultivator, suitable for work in restricted areas, including commercial glasshouses. (Kubota)

Fig. 16.5 Below: Offset rotary cultivator working in citrus fruit orchard.



Fig. 16.4 The 1120 11 kW model (14.5 DIN hp) is smallest in the Ford Series 20 Compact range. It is shown here with a sturdy rotary mower designed for use where the going is rough and access difficult. (Ford New Holland)





Fig. 16.6 Narrow-track specialist vineyard tractor using air-assisted-delivery sprayer. Work in the narrow rows is assisted by specialist tyre profiles and all-round guards. (*Massey-Ferguson*)

turers' compact tractors tend to be in groups of three, e.g. small 12 kW; medium 18 kW and large 24 kW. The main technical features of interest to prospective users begin with ease of driving the basic vehicle. Whereas one manufacturer (John Deere) provides a pedal operated two-range hydrostatic transmission with cruise control on the top of range (24 kW) model, another (Case I-H) offers the option of either hand-operated or foot-operated hydro drive on only the lowest powered of its current range (17 DIN hp (14 kW)). Other features of high importance are the ease with which front-, mid- or rear-mounted equipment is connected to the power unit and adjusted for work; and ease of raising it out of work and manoeuvring round obstacles. A roll-over protection bar is usually a standard fitting, and four-wheel drive commonly an option. The easy availability of first-class equipment for use with the tractor often decides the real value of the tractor to its purchaser.

Soil sterilising equipment

Soil may be sterilised either by chemical means or by heating. Chemical methods do not involve the use of

expensive equipment, but they are rather limited in their action. Heating the soil to a sufficient temperature, on the other hand, not only kills all pests and diseases, but increases fertility at the same time.

Small quantities of soil may be heated in various ways, but the normal method used for the soil in commercial glasshouses is steaming. Boilers commonly used for this purpose include portable loco-types, preferably with forced draught and high steam-raising capacity of 450–900 kg (1000 to 2000 lb) steam/hour; but much cheaper, smaller types, with a maximum output of about 270 kg (600 lb) per hour, can be successfully used provided that the operating principles are properly understood.

The steam is delivered to the soil by means of perforated iron pipes which are buried by hand digging, or a harrow grid with hollow perforated tines for use in freshly tilled soil. The harrow grid method is better adapted to mechanisation of cultivation, but the method hitherto generally preferred is, briefly, to excavate a trench to a depth of 300–450 mm (12 to 18 in); lay in one or more perforated pipes (Hoddesdon pipes) 450–500 mm (18 to 20 in) apart; cover with the soil from the next trench, then cover with a tarpaulin, and pass steam until the temperature of all the soil reaches boiling point. The modern method is to use a winch-operated steaming plough, which is moved steadily through the previously tilled soil. When steam is passed into soil that has been well broken up, it at first condenses on the soil particles surrounding the pipe. As more steam is passed in, the soil near the pipe is raised to boiling point, and the steam then passes through, and condenses farther away from the pipe. For efficient steaming, the flow of steam must be just sufficient to cause the heated layer to advance upwards at a steady rate. An excessive rate of steaming is wasteful, because the surplus which cannot be condensed rapidly enough finds its way to the surface as steam, instead of delivering up its heat to the soil. In general, the steaming rate for economic operation should be such that it takes 20 min or more for the surface soil to reach boiling point. If then the steam is turned off, and the cover left on for a further 5 min, sterilisation will be effectively achieved. Near concrete and wet patches, the steam should be passed slowly for a further 5 min after the surface is cooked. As with dairy boilers, there is no virtue in high pressures as such. A loco-type boiler, working at a pressure of 5.5 bar (80 psi) or more, should be used with a water trap and pressure-reducing valve close to the Hoddesdon pipes.

The area that can be sterilised in a given time is not reduced by working at a low pressure. The lower pressure results in more time being taken to cook a particular part of the soil, but more pipes can be employed on the same boiler. Steam mains should be well lagged and as short as possible, with no steam leaks. A small boiler with an output of 270 kg (600 lb)/hour can work quite economically at a pressure of 0.7 bar (10 psi), with a 50 mm (2 in) main up to 30 m (100 ft) long and a grid of two pipes only.

For fuel economy, the soil should be as dry as possible, since much of the steam's heat is used in raising the temperature of the soil moisture, which has a high specific heat.

Compost shredders and mixers

The preparation on a large scale of uniform potting compost is greatly assisted by use of a compost shredding machine. A typical machine has an inclined hopper, the lower side of which consists of a high-speed combing belt. The endless rubber belt is covered with steel teeth and driven by a built-in electric motor or petrol engine. As the belt moves upwards through the hopper, its surface combs and shreds the material until it is fine enough to pass out in a thin layer through the opening between the belt and the upper end of the hopper. The shredded material is thrown from the machine by the speed of the belt, and may be delivered into a large heap or deflected into a container. Mixing may be achieved by putting the various constituents through the machine together.

When manure compost for application to the land or for making mushroom beds is being prepared, some ordinary farm manure handling equipment may be used with advantage. For example, a tractor-mounted hydraulic loader with manure bucket may be employed to put the long compost into a stationary pto-driven flail-type farmyard manure spreader, the spreader being arranged to deliver the compost into a heap after shredding it. If the need to do this job occurs frequently, it may be worthwhile to equip the spreader with electric motor drive, or to invest in a compost shredder expressly designed for such work as preparing mushroom beds. A typical medium-sized machine has a feeding elevator, a large revolving drum incorporating a wetting zone and a stacking elevator with a hopper above it for the addition of chemical fer-

tilisers. At the top of the elevator a high-speed spinner breaks up the compost and throws the mixture on to a heap.

Soil block-making machines

Soil block-making machines consist essentially of a mould and a press, designed to make moist potting compost into firm blocks in which seedlings are planted for propagation, no pot being required. The blocks are usually hexagonal in shape, as this allows them to be stacked close together. The dimensions normally used for tomato seedlings are 75 mm (3 in) across the parallel sides of the hexagon, and about 100 mm (4 in) high; but much smaller blocks (e.g. 50 × 50 mm (2 × 2 in)) may be employed for other crops. John Innes compost makes good soil blocks if the loam is sufficiently fibrous, and the mixture just wet enough. The moist compost, which should be at a temperature of about 15°C (60°F), is vibrated into the moulds until they are full. Pressure is then applied by a plunger which compresses the blocks and sometimes makes a small planting cup in the top of each. In other models, the seedling is held in position while the block is being made. The mould has a removable bottom, and the blocks are pushed out ready for use. The range of equipment now available includes machines which make blocks of various shapes and sizes, in batches of one, four, six, eight or more at a time, or continuously.

Blocks contain more compost than the pots which they replace, and results show that the crops propagated in them often grow away better than those from pots. Block-making machines can eliminate all the troubles of providing, carrying, cleaning up and washing pots, and are widely used.

Orchard equipment

Some of the most important machines used in orchards, i.e. grass cutters and sprayers, are dealt with in Chapters 11 and 9 respectively. Pruning absorbs a great deal of labour, and many power-operated devices such as mobile pruning platforms and pneumatic or hydraulic pruners have been developed, and are more widely used in some foreign countries than in Britain. Clearing up after pruning is usually done either by hand or with a buckrake.



Fig. 16.7 Heavy-duty flail chopper used to pulverise prunings in a grass orchard.

One method of disposal is to use a machine which chops up the branches into small pieces. A typical machine has four banks of heavy-duty flails which pass between interceptor bars in order to produce a thorough chopping action (Fig. 16.7).

Mechanical harvesting of fruit

Mechanical harvesting equipment tends to be designed mainly for fruit which is to be processed, rather than for the fresh market. It has been particularly applied in the USA to crops such as cherries, and in Europe to olives. The main types of equipment used are combing devices and vibrators.

In Britain, blackcurrant harvesting has been successfully mechanised, using shaking equipment. Machines available include tractor-trailed equipment designed to work half a row at a time, and self-propelled harvesters which straddle and pick a complete row. Work rate with a trailed machine is about 6–10 tons/day. Self-propelled harvesters can do over 20 tons/day. The mixture of fruit and leaves passes through pneumatic separators to remove light rubbish. The product, which is stacked in boxes on a trailer or trailers drawn behind the harvester, can be drier than hand-picked fruit.

Where harvesting is to be mechanised, bushes should be planted close together in rows about 2.7 m (9 ft) apart. The tractor used for a trailed harvester needs a forward speed of about 0.8 km/h ($\frac{1}{2}$ mph), and must be fitted with guards.

Though it is possible for raspberries, gooseberries, etc. to be picked mechanically by machines of a generally similar type, commercial incentives in Britain are greatly discouraged by the wide adoption of 'pick-your-own' marketing.

Commercial use of tree-shakers started in the USA many years ago with walnuts and almonds, and was later extended to other fruits, notably olives, acid cherries, prunes and plums. 'Impact' knockers were originally used, and still are for old almond trees. A padded shaker head imparts discrete axial blows. Later, fixed-stroke boom shakers which were clamped to the tree and driven by a cam or eccentric were used. Most modern shakers are of the 'inertia' type. The vibration is usually produced by eccentric counter-rotating weights which are generally co-axial and one above the other.

Another type of mechanism employs a slider-crank



Fig. 16.8 Self-propelled blackcurrant harvester with hydraulically operated inertia shaker fingers. The same type of harvesters can be used for redcurrants, and with similar shaker units for gooseberries and grapes. The basic chassis can be used for spraying these and similar crops.

arrangement. Many variations of stroke length and frequency have been tried. Most tractor machines use a frequency in the region of 1000 cycles/minute and a stroke length of about 38 mm ($1\frac{1}{2}$ in). Duration of shaking must be limited to about 3–5 seconds, or two or three bursts of 1–2 seconds.

Vibrators are particularly applicable to the harvesting of cherries and plums, since the force required to strip the fruit from the stalks decreases as the fruit ripens, and so permits selective harvesting.

Effective application of tree shakers necessitates the use of easily operated catching and collecting devices. These usually consist of canvas or nylon sheets on easily moved catching frames. Among the more sophisticated devices are inflatable cushions into which air is automatically pumped as the mattress is spread out. One type of collector has nylon sheets carried on a wheeled chassis which can be hydraulically steered into position from the tractor seat. The chassis incorporates a conveyor, a separator for removing leaves and trash and mechanised collection of the fruit. Tree shakers cannot at present be economically applied to apple harvesting, owing to the difficulty of avoiding excessive bruising. They are widely used for olives.

Grading machinery

Grading for size and quality is an essential preliminary to marketing of fruit and vegetables grown on commercial holdings, and many types of machine are available to assist this work. Some are cheap and simple sizing or weighing machines for grading produce which has been sorted for quality beforehand. Others are complex and expensive machines which incorporate devices to facilitate sorting for quality, accurate sizing mechanisms and bins to facilitate packing.

Mechanisms employed to assist sorting for quality include roller feed conveyors, which turn the produce over as it passes in front of operators, who pick out rejects. This method is advantageous where a large throughput is an important objective, and a small proportion of blemished produce in the pack is not serious. An alternative method, by which the operators pick up each item individually and put it, according to quality grading, into the appropriate section of the size grading, usually gives a lower throughput. On some machines employing the

second method (e.g. the Jansen) the operators sort direct from the boxes, while on others the produce continues to pass in front of the operators on a sorting belt until it is picked off and placed in the appropriate section of the sizing mechanism.

Sizing mechanisms may be grouped broadly into those which grade by diameter and those which grade by weight. Machines which grade by diameter vary greatly. Some size in only one or two directions, while others rotate the produce and thereby achieve a more accurate sizing. In general, machines that grade by diameter tend to have higher throughputs, or to be rather less expensive for a given throughput, than those which grade by weight. On the other hand, a good weight grader has many advantages. It can be used for any shape, is easily adjustable and can be used for crops that are easily blemished. Grading by weight can also be more accurate than grading by diameter, though good diameter-type graders are usually accurate enough for practical purposes.

Good graders do little damage to apples, most of the bruising that does occur being caused when the fruit rolls into the receiving bin. This is usually negligible compared with damage incurred in picking, and getting fruit to the grader.

Throughputs of graders vary widely according to the number and ability of the operators, as well as according to the machines and auxiliary equipment employed. Some graders are equipped with automatic box-tipping devices for loading. The graders in large-scale apple-packing stations are often fed by first immersing the boxes in water and then handling the fruit on to the drier by flotation. Throughputs on such high-speed machines are frequently limited by the speed of packing.

No one grading machine has all the advantages, so choice of a grader requires careful consideration of the most important needs for the conditions in which it is to be used. In the brief description of types of mechanism which follows, it is not possible to give an adequate description of any individual machine.

Size graders

(a) *Produce falls through a circular hole of fixed size.* In machines of this type the sizing board has a number of rows of holes of different sizes, and the crop is carried along by means of a series of wooden laths operated by a crank mechanism. The effect is to move the produce,



Fig. 16.9 Diverging-roller type of vegetable grader suitable for elongated produce. The installation shown includes belt conveyors and weighing scales for three grades.

without pushing or rolling it, to successively larger holes, until it falls through.

(b) *As produce moves along conveyor, size of opening increases.* Graders with mechanisms of this type are common, and include apple graders, in which the fruit is rapidly rolled along by a soft rubber belt, while leaning against a rubber barrier set at a gradually increasing distance from the belt, and machines with diverging rubber belts.

Weight graders

In weight graders, each fruit rests in an individual hinged cup, and for much of the journey along the conveyor the cup and fruit are supported in an upright position by a fixed guide rail. At suitable intervals, however, the support is provided by an adjustable lever-type weighing device. When the moment exerted by fruit and cup is sufficient, the cup tips, and deposits the fruit into its appropriate bin.

Vegetable washing machines

It has long been realised by progressive growers that financial returns can depend on the manner in which produce is prepared and packed for market. Even first-grade vegetables may realise an unsatisfactory price unless they are trimmed, washed and properly packed. Manual methods of washing, in a tank of water or with a hose-pipe may be economic on small holdings, but growers on a large scale need labour-saving washing machines. Vegetable washers of many types have been developed to suit various crops, and the methods employed are briefly discussed below. They must depend primarily on the type of crop to be handled, but of equal importance is the quantity of water available, which in turn influences the means adopted to deal with the dirty water. The principal methods adopted in washing machines are (a) spray jets, (b) mechanisms for 'tumbling' the vegetables in the presence of water and (c) scrubbing. Individual machines employ any one of these methods or a combination of them. In addition, many machines employ a soak tank, either before or during the washing process, and most continuous-process machines have a final 'picking-over' conveyor which enables any blemished vegetables to be removed before packing.

Jet washers

Where plenty of water is available, or easily damaged crops are to be handled, the vegetables may be moved on an endless conveyor through a spray chamber, where they are exposed to jets of water. The type of conveyor usually employed on commercial machines consists of a roughly horizontal endless belt. A pre-soak tank assists the action of spray jets, and can fairly easily be incorporated in some types of endless belt machine. A further refinement is a roller conveyor that gently turns the crop as it passes through the chamber.

'Tumbler' machines

Rotary tumbler machines with spray jets or with brushes and jets are used mainly for carrots. The tumbler mechanism consists of a nearly horizontal rotating cylinder of wire mesh, and spray jets are directed on to the crop as the cylinder revolves.

One type of rotary tumbler machine has the rotary

drum partially submerged in a soak-tank. The water has a cushioning effect, and such machines, with a mechanism designed to handle crops gently, can be satisfactorily used for many types of vegetable.

Continuous-process rotary tumbler machines are normally equipped with a short belt conveyor for picking over and bagging-off.

Scrubbers

Some washers expressly designed for carrots employ a mechanical scrubbing process. One type scrubs the carrots under water as they pass along a horizontal conveyor trough. The mechanism employed in this case consists of a reciprocating brush which resembles an inverted door-mat. Other types of scrubbing machine use circular revolving brushes. Contra-rotating cylindrical brushes may work inside the cylinder just above the layer of carrots. High volumes spray jets operate in conjunction with the brushes.

Water supply, drainage and installation problems

Whatever type of vegetable washer is chosen, problems of water supply and drainage need consideration. Machines which do not use high-pressure jets require a minimum of water, and are therefore suitable for use in the field where water has to be carted. Machines requiring a large volume of water tend to create a drainage problem. Where the water supply is drawn from a nearby stream, it may be returned by an open furrow of gentle slope, which gives the soil opportunity to settle out.

With fixed washing machine installations of types that need to use a large volume of water, limitations of water supply, or a high cost, may necessitate some economy in the total amount of water used. Such considerations, together with the need to keep mud out of the drains, may make it essential to construct a settling tank and filter system which allow the water to be used repeatedly.

If a washing machine is to be installed in a packing shed, it is necessary to plan the layout so that the dirty side of the process is well separated from the clean, and to allow plenty of light and room for sorting and packing. Layouts should allow efficient use of fork-lift vehicles for pallet handling, and loading road transport trucks.

Where potatoes are washed and pre-packed there is much to be said for the use of a flume system for conveying

the tubers from permanent or temporary storage to the washing machine. A low-pressure jet of water is used to wash the tubers into channels which lead to a large sump near the washer. Fluming leaves the store clean, saves labour, avoids handling damage and improves the performance of the washing machine.

A typical flume is a channel 300 mm wide at the top, 200 mm wide at the bottom and 200 mm deep at the upper end ($12 \times 8 \times 8$ in). Depth is greater nearer to the large sump into which the flume leads, at a slope of 1:180. For a packing rate of 5 tons per hour, the pump for fluming needs to provide about 1000–1100 l/m (220–240 gal/min). Potato flow rates should not exceed 18 m (60 ft)/min, 4.5–9 m (15–30 ft)/min being ideal. The sump is an important part of the fluming installation. Prefabricated steel sumps complete with the necessary drainage cocks and elevator for delivering the tubers to the washer are available.

Hop-picking machines

Development of the use of hop-picking machines in Britain was rapid, and hand picking has been superseded. Machine manufacturers strive to reduce breakage and loss to a minimum, while attempting to make picking and separation completely automatic. The percentage of leaf and stem in machine-picked samples can be kept low by allowing some wastage of hop material in the cleaning processes. Fortunately, some of the best new varieties of hops are very suitable for machine picking.

Most of the machines in commercial use are of large or fairly large stationary types. The hops are cut and carted to the machine as 'strings'. The strings are attached separately by their lower ends to hooks or automatic bine clamps on an overhead conveyor chain which carries them head down through the main picker and on to waste disposal. In the main picker hops and leaves are stripped off the string by plucker banks which usually consist of contra-rotating cylinders or drums with a combination of long spring fingers and shorter steel loops designed to penetrate and gently pick dense foliage without wrapping it round the drums. The main picker inevitably pulls off some lateral branches which fall with single cones, bunches of cones and leaves on to a spaced roller conveyor.

From there laterals are gripped by endless chains to

pass through further sets of picking fingers in the automatic lateral or spray picker. Bunches of cones pass on the roller conveyor to pairs of soft rubber rollers mounted above and just touching the spaced steel rollers. Each pair of rubber rollers passes bunches between them to the next pair. Successive pairs are driven faster, and the differential speed plucks off the cones which then fall through the main conveyor to a belt for cleaning.

The cleaning system consists of a variety of mechanisms for separating out the pieces of broken stem and leaves from the hops. Use is made of wire mesh screens to remove small pieces of stem and leaf, while light fractions are separated by aspiration. Pieces of leaf and stem are separated from whole hops by means of inclined conveyors. The hops roll down the adjustable incline, while the flatter rubbish is carried up on the studded belt. After all this, hand-sorting is done on the final conveyor, removing any big pieces of stem and leaf from the final sample.

A typical medium-sized stationary machine is suited to the needs of growers with about 8 ha (20 acres) of hops. Maximum area that such a machine can handle is about 14 ha (35 acres). Smaller machines can deal with 4–8 ha (10–20 acres) effectively and economically. Saving of labour by the machine is considerable: a gang of 20 with a good machine can do as much work as about 200 hand pickers.

The rate of feeding strings into a medium-sized machine is 12–24 per min. It is essential to maintain a steady flow of strings to and through the machine, and this necessitates a good field gang and transport system. The machine as a whole needs fairly constant supervision and frequent adjustment, since the condition of the crop invariably alters as the day progresses. Crops are at their best for picking for only about 10 days, so it is advisable to grow varieties which ripen in succession.

The introduction of a successful tractor-mounted bine loader has revolutionised the field work at harvest on farms where large pickers are used. The 'Trumpet' bine loader, developed from the German 'Wolf', is side-mounted on a small to medium tractor which tows special-purpose bine trailers, sometimes home-constructed on a narrow chassis. An essential need is that the stringing be designed for the machine: 'Worcester' work with two strings per hill, diverging both laterally and longitudinally so that half of each row is loaded in one direction and half in the opposite direction, with the tops of the strings



Fig. 16.10 Hop bine loader showing mounting on conventional medium-powered tractor; gathering jaws and bine-gripping chains at front of machine; guard rails to guide 'strings' clear of tractor; and horizontal section of track running to centre-line where the string is tightly gripped and pulled from the overhead wires. (CWF Trumpet)

inclined towards the loader, is most suitable. The hydraulic-drive loader is driven forward continuously when loading. It consists of (a) a V-guide with pinch chains to grip the lower part of the 'string' and cut it; (b) a pair of inclined gripping reinforced rubber belts which progressively raise the lower part of the string while maintaining a light pull; (c) a short horizontal transverse length to a point above the trailer drawbar; there the pull increases and breaks the string from the wire at the top. A man working at the front of the trailer can secure a tidy arrangement of the load. Work rate can be up to 1000 strings per hour when needed. The machine commonly saves several men in the field and at least another at the picker.

Bulb-lifting machines

Bulbs are now usually lifted by a specially modified potato elevator digger or a complete potato harvester. Many modern harvesters can do excellent work when fitted

with webs of a size suited to the crop. In these circumstances the older methods of hand picking are rapidly being superseded.

Vegetable harvesting

Harvesting vegetables by hand typically accounts for a quarter to nearly three-quarters of the total cost of vegetable production. With most crops, a mechanised harvesting technique is only really satisfactory where the whole crop can be removed in a 'once-over' operation. Selective harvesting of some crops is possible, but it is much more difficult. The trend is therefore towards development of crops which are very uniform in respect of date of maturity. Peas, green beans and Brussels sprouts have been bred to suit once-over harvesting, and rapid developments in use of mechanical harvesters are taking place in many countries where mechanisation is at an advanced level.

Most vegetable harvesters are special-purpose machines, designed not only for one type of crop, but often for one crop grown in a particular way. For example, a special-purpose carrot harvester may be designed specifically for dealing with a broad band up to about 125 mm (5 in) wide, or two to three rows of equivalent width, with a wide space between this band and the next.

Green pea harvesting

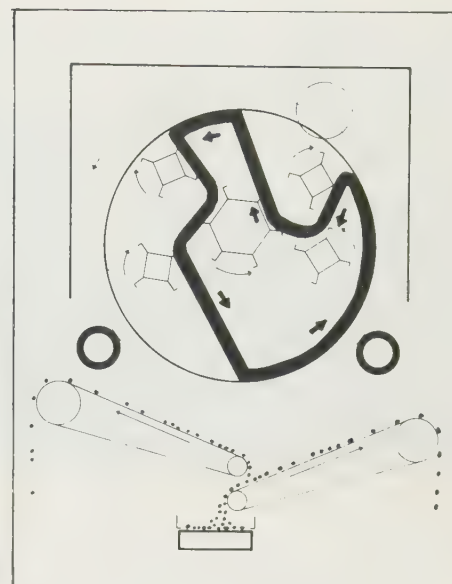
Changes in green pea harvesting systems illustrate the rapidity with which new techniques can succeed one another in highly developed countries.

When the pea freezing industry was first established alongside canning, the first shelling machines used were stationary viners which usually served farms within a radius of 16 to 32 km (10–20 miles). Difficulties in cutting, loading and transporting the haulm with pods attached, and with threshing and chilling the peas were soon overcome; but delays between cutting and threshing, which spoil the quality of the product, and a vast amount of unproductive transport work were often inevitable. When mobile viners that worked on a windrowed crop became available the sale of new stationary viners soon ended. The mobiles leave the threshed haulm in the field where it can be ploughed in if not required for silage or hay.



Fig. 16.11 Six-wheel drive low ground pressure pod-picker SP pea harvester at work. (FMC 979).

Right: Sectional diagram. Heavy line shows flow of haulm and pods during threshing, viz. between planetary beaters on right;



up via main beater to top centre; and down to bottom centre via left planetary beaters. Small pieces of rubbish are taken out of the riddled crop by the sloping belts.

In their turn, the windrow-pick-up mobile harvesters were replaced as fast as economically practicable by self-propelled 'pod-picking' types.

Pod-picker pea harvesters

Developments in the successful British-made FMC 979, which weighs 23 t include a change from four-wheel-drive to three axles and six-wheel hydrostatic drive using suitable LGP tyres. This satisfies UK and EC road transport regulations and gives the valuable added benefit of about 20% reduction in pressure exerted on the soil compared with the earlier 4-W-D 879 model. Power is provided by a Deutz 225 kW (300 hp) air-cooled engine, used primarily for the fully hydrostatic Sauer pumps and Poclain motors for the wheel drives, but also for the many other hydraulic drives required for the picking, threshing, cleaning and conveying. Advanced hydraulic load sensing technology is employed to ensure that on selected circuits, when pumps are not required to supply oil they are automatically shut down, coming back on delivery auto-

matically 'on demand'. Exports account for a healthy proportion of total sales.

The trend in pea harvesting is strongly towards self-propelled harvesters that pick the pods from the uncut crop, thresh and clean in one operation. In comparison with the windrowing technique this system reduces labour need, speeds up the work and reduces field losses.

In a typical harvester (e.g. FMC; and Shelbourne Reynolds) the main components are: picking reel, conveyors to the threshing drum, cleaning mechanisms and a hydraulically raised and tipped pea hopper. The reel employs a combing action, stripping off the pods and some attached pieces of vine. Height of the spring tines is hydraulically adjusted, and setting in relation to the ground may be automatically maintained by use of a ground-following roller at the rear of the reel. An enclosed belt conveying system collects pods, shelled peas and vine and delivers them to the threshing drum. The beater system is different from that employed in a viner designed for use after windrowing. In the FMC harvester four 'planetary' beaters are used in conjunction with a central

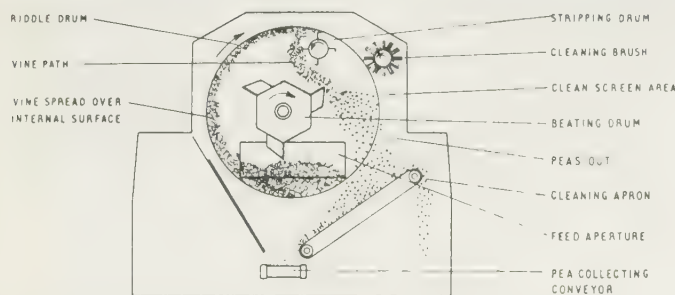


Fig. 16.12 Above: Pod-picking self-propelled green pea harvester at work.

Below: Section shows flow through the threshing drum, viz. up the left side to top centre, where the stripping drum throws the haulm to the main beater. (Shelbourne Reynolds SB 8000)

beater to give six impacts per revolution of the drum. The Shelbourne Reynolds employs in addition to the main beater a stripping drum that peels the layer of pods and haulm off the screen near the top, throwing them in the path of the main beater. Pod-picking harvesters employ a full-length external brush to clean the mesh of the revolving screen. The whole threshing and separation mechanism is automatically levelled on side slopes by up to about 12° , and fore-and-aft by up to about 10° . The shelled peas pass over full-length inclined cleaning aprons and are then cleaned by a succession of suction fans to remove light leaves and by a mesh chain to take off unthreshed pods for rethreshing.

Dwarf green bean harvesters

Green beans for freezing can be harvested by machine provided that suitable varieties are grown and correct cultural methods employed. The harvesters employed in Britain are mainly of British or Dutch development, and range in complexity from a single-row trailed type to self-propelled harvesters with a working width of 3 m (10 ft). All operate on similar principles. Spring-steel fingers pull the beans off the plants without cutting or uprooting them. Many leaves are stripped off with the beans, but these are easily removed by aspiration, while any short pieces of stem are readily screened out.

Large-scale users tend to favour specialist self-propelled machines. Technical advantages of the S-P type include a larger-diameter and wider picking reel, which leads to more thorough picking and a higher output. In a British harvester (FMC – Fig. 16.13(a)) an inclined power-driven full-width belt presses the crop down so that the heads are picked first from top to bottom, and then as the reel passes over the plants, from bottom to top. Powerful fans remove the light leaves and deliver them down to the ground behind the picker unit. The beans are conveyed to the top of the machine for further cleaning, and collected in a large (2.5 tonne) hydraulically tipped hopper. Hydraulic drive to every component and a hydrostatic



Fig. 16.13(a) Self-propelled hydraulically driven green bean harvester at work. (FMC)

transmission provide a degree of control not attainable in less sophisticated harvesters. The capacity of such machines is above 200 ha (500 acres) per season.

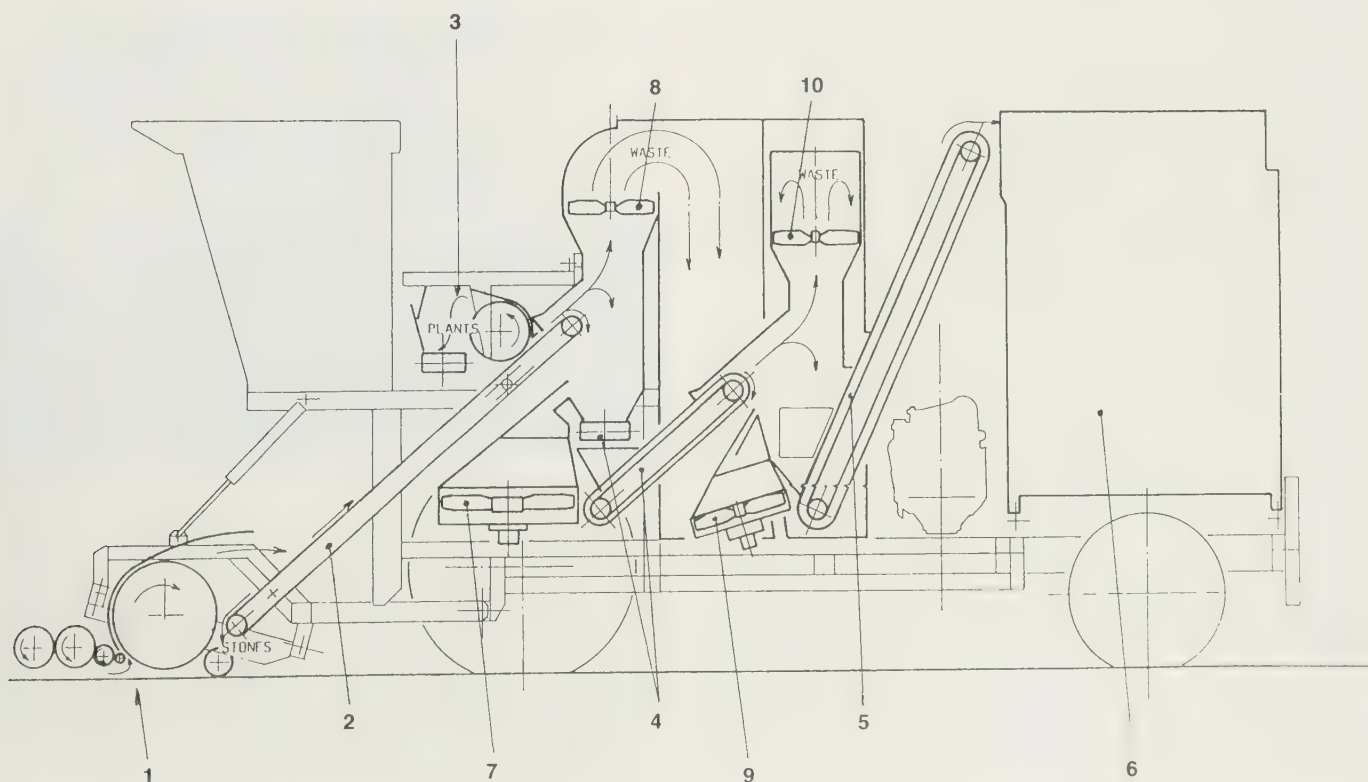
A successor to the British designed and manufactured green bean harvester is the French-made Mather and Platt BH 6100, illustrated by a simple crop-flow diagram in Fig. 16.13(b). It has a 230 hp turbo-charged water-cooled diesel engine with four-wheel-drive and hydrostatic steering. It operates on the now proven principle of using a double combination of pressure and suction fans for the main cleaning processes.

Brussels sprout harvesters

Sprouts can be successfully harvested with the help of various mechanical devices, provided that suitable varieties are grown and appropriate cultivation methods are employed. It is essential to ensure that most of the stems grow to a marketable size at the same time. The crop must also stand well, so as to allow 3–4 weeks for harvesting a crop which is sown, planted and stopped at a particular time. Recommended spacing is usually 530 mm (21 in) both ways.

Fig. 16.13(b) Sectional diagram showing crop flow and cleaning processes in self-propelled green bean harvester manufactured by Mather and Platt, France. 1 Picking unit, 2 Feed elevator, 3 Plants and clusters extraction, 4 Transfer

conveyors, 5 Flight elevator to 6 tipping hopper, 7 First stage pressure fan, 8 First stage suction fan (blowings to waste), 9 Second stage pressure fan, 10 Second stage suction fan (blowings to waste). (FMC/Mather and Platt BH 6100)



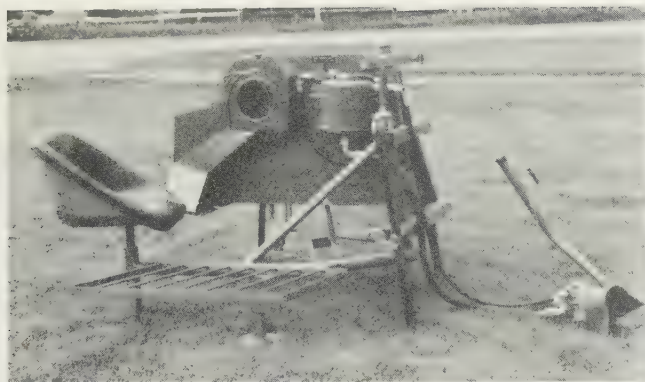


Fig. 16.14 Brussels sprout harvesting equipment. (*Lodgeway/Jamafa*)

Basic three-point linkage stripping unit with built-in pto driven hydraulic power unit, operator's seat and a simple feed table. Options include a pivoting 4 m feed belt and raised position to accommodate pallet box and canopy to assist two-man operation.

Strippers are used for removing sprouts from the stems, and cleaner/graders for preparing a sample for processing or for market.

An important feature of any machine is the stripping head. In a tractor-mounted example (e.g. Jamafa) use of a pedal by the operator stops the head rotating and opens the trimming knives to receive the cut end of the stalk. When about 100 mm of stalk has entered, it is gripped by rollers which pull it through the rotating knives. The knives, assisted by spring pressure, follow the contours of the stalk and separate buttons from leaves during the stripping operation. The stripping unit has a self-contained pto-operated hydraulic drive requiring about 7 hp. For tractor-mounted machines which stop to work, two operators are needed, one to place cut stalks on a handy feed table which holds a small supply, and the other to feed stalks into the stripper. The sprouts are bagged in 10 kg nets. Many users buy a 4 m feed belt to reduce the frequency of tractor moves, so improving the work rate of the two men.

Self-propelled tracklaying harvesters have many labour-saving aids; e.g. automatic braking of the stripping head and opening of the trimming knives by a light beam and electronic sensor which come into operation as a stalk is presented to the rotating head; a hydraulically tipped bunker hopper; and automatic stalk shredding.

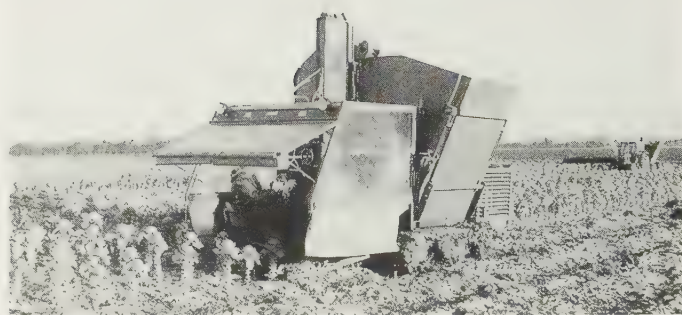


Fig. 16.15 Sprout harvester, Jamafa two-head track model. Two-man, two-row self-propelled Brussels sprouts harvester carried on short elastic polyurethane tracks, largely self-steering in work. Picture shows hand-deleafed plants and general view of front-open cabin having two mainly inward-facing operators. A vertical sprout elevator delivers to a 5 m³ bunker fitted with leaf-blower and capable of sideways hydraulic tipping into road transport. Position of 40 kW Ford industrial diesel engine and hydrostatic drive unit can be seen at rear.



Fig. 16.16 Front-open cabin of Jamafa two-head track model. Close-up of the two patented Jamafa picking units operated partly by foot pedal but with electronic light-beam proximity sensor. Auto-pilot steering during work on straight rows. Adjustable stalk cutting saws (2) for row spacings 50–75 cm. The new harvester is a high-specification machine with full travel and work lighting; traffic indicators and warning flasher; heating; radio; bunker full warning; step-less speed regulation up to 7 km/h; two automatic stalk choppers, and road transport on built-in pneumatic tyres; tractor-towed. (*Lodgeway/Jamafa 2-row SP Track Model*).

Important advances have been made in design of the two-row, two-man Jamafa tracklayers, based on experience with the earlier 3-row track-mounted machine. By weight-saving wherever possible, and restricting the number of moving parts, it has been found that a relatively short track made of a new light material can be successfully used, resulting in a two-man output approximately 15% higher than expected, and also a saving on maintenance costs (see Figs 16.15 and 16.16).

Cabbage harvesters

Drumhead-type cabbages can be easily harvested on a bulk-handling system. Two main types of equipment are

used in some Eastern European countries. The simplest consists of a rear-mounted endless-belt conveyor-elevator that works just ahead of a hand-cutting gang and provides a labour-saving handling system suitable for selective harvesting. A more complex type of machine provides mechanised cutting and trimming on a once-over system.

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Seed Cleaning and Feed Preparation

This chapter contains a brief account of machines used for cleaning grain and seed crops and for preparing feed for livestock. Some items of barn machinery including mechanical gutter cleaners and silage feeding equipment are dealt with in other chapters.

Grain cleaning and grading machinery

The sample of grain delivered from combine harvesters can often be much improved by a further dressing in special cleaning and grading machines. When corn is required for seed, the advantages of sowing a clean uniform sample are obvious, and a further dressing after threshing is usually essential. The removal of weed seeds reduces cultivation costs and gives increased yields, while drills function much better when clean and properly graded seed is used.

The price received for grain or other seed that is for sale, particularly in the case of crops such as malting barley, may often be substantially increased by a relatively insignificant expenditure on cleaning and grading.

Grain from combine harvesters frequently contains green leaves and thistle heads, as well as chaff, pieces of straw, a good deal of dust and often many insects. In such cases it is usually essential to subject the grain to a cleaning process before it is stored. If the grain needs drying it is often advisable to pass it through a pre-cleaner before drying and through another cleaning and grading machine afterwards. The first operation removes those coarse impurities which are likely to interfere with the drying process. After drying, impurities are much more easily removed, and a final dressing can produce a clean and well-graded sample. The term 'pre-cleaner' is correctly applied to a machine which carries out a preliminary operation, rather than to any particular type of cleaning machine.

The object of using a cleaning machine is to separate from the grain all chaff, straw, weed seeds, broken and inferior seeds, dust and other rubbish; many machines also grade the grain according to size into the various samples required.

Seed cleaners range from very simple riddling or winnowing machines to complex dressers which treat the grain in many ways. The processes commonly employed on farm machines are as follows:

Screening over a sieve with large holes or endless mesh belt to remove stalks, stones and other large roughage.

Separation by air blast, either with a simple winnowing device or by aspiration.

Use of nests of sieves or rotary screens to separate grain according to its width.

Use of pockets (e.g. indented cylinders) to separate grain according to length.

Seed merchants use special methods for grass and clover seed, and for the removal of particular types of impurity from all kinds of crops. Such machines may make use of differences in surface characteristics, while one type of electronic machine makes use of differences in colour for a final sorting of leguminous seeds.

The simplest form of cleaner may carry out only one of the above processes: e.g. a simple pre-cleaner may consist of only a single reciprocating sieve, or an endless woven-wire belt, or may be a simple aspirating cleaner. The most complicated cleaners may employ all the processes detailed above.

Sieve cleaners

Sieve cleaners which achieve separation without using an air blast are uncommon, but were formerly sometimes installed as pre-cleaners in conjunction with tower-type

grain dryers. Their chief disadvantage is a tendency to blocking of the sieve or sieves — a fault which necessitates frequent inspection and attention when dirty samples of grain are being dealt with. A steep sieve angle helps to prevent such troubles.

The sieves on these, and also on more complex combined machines, are usually supported on ash hangers and driven by an eccentric or crank. They have mainly a horizontal motion, but there is also a slight vertical motion which helps to keep the sieves clean. On the more complex machines, the angle of the sieves may be adjustable. Cleaning brushes are fitted. There are considerable variations between different manufacturers in such factors as the amount of vibration, and the degree of uniformity with which the grain is spread over the width of the sieves.

Endless woven-wire pre-cleaners

One type of pre-cleaner makes use of an endless belt consisting of wire mesh which travels at a fairly high speed. The sample is introduced into the machine in such a way that long pieces of straw, string, etc., tend to lie flat on the belt. These are carried along by it, and thrown

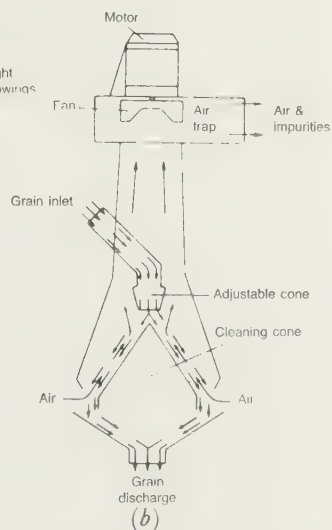
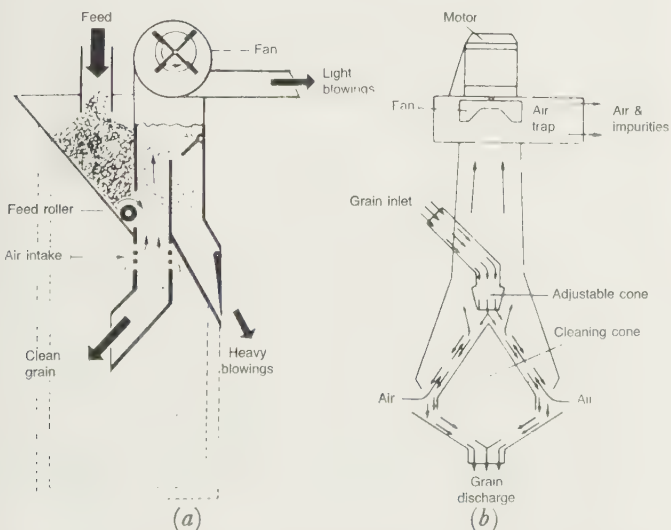


Fig. 17.1 (a) Principle of simple aspirator. The light blowings are conveyed by trunking to a dust chamber or cyclone outside the building.

(b) Section of cone-shaped aspirator showing mode of action.

off the end as the belt rounds pulleys. This type of moving sieve is normally used in conjunction with aspiration to remove chaff and dust. The complete pre-cleaner usually has a high capacity and is very free from blockages.

Winnowers

In a simple winnowing machine the blast of air from a fan which rotates rapidly inside a suitable casing is directed on to the grain as the latter falls in a thin stream from a hopper at the top of the machine, on to reciprocating sieves. The blast blows chaff and other light material through the open end of the machine, while small corn, weed seeds and dirt pass through the lower sieve. The dressing may be controlled by choice of the sieves, the strength of the air blast and the rate at which the grain passes through the machine.

The chief disadvantage of the winnower, apart from its limitations, is the fact that unless special arrangements are made for dealing with it, the dust blown out may be an intolerable nuisance. This disadvantage applies not only to the simplest winnowers, but also to any more complex dressing machines that employ the winnowing process. The remedy, which must be borne in mind when planning any installation that employs such machines, is to arrange to blow the cleanings into a large settling box which has a wire-covered outlet of adequate size on the outside of the building, and is arranged so that it is easy to clean out. Unless this requirement is borne in mind at the outset, expensive modifications may become necessary.

Aspirating machines

Many simple pre-cleaners rely for separation on passing the crop into a vertical air current which lifts chaff, dust and other light contaminants and allows the sound grain to fall through the air-stream.

Aspiration is much more selective than an unconfined horizontal air blast directed at a curtain of grain, and is to be preferred if properly applied. The light materials can easily be conveyed to a suitable point for collection.

Combined aspirating and sieving machines

Many of the complex cleaning and grading machines now used on farms, and also by seedsmen, employ a combi-

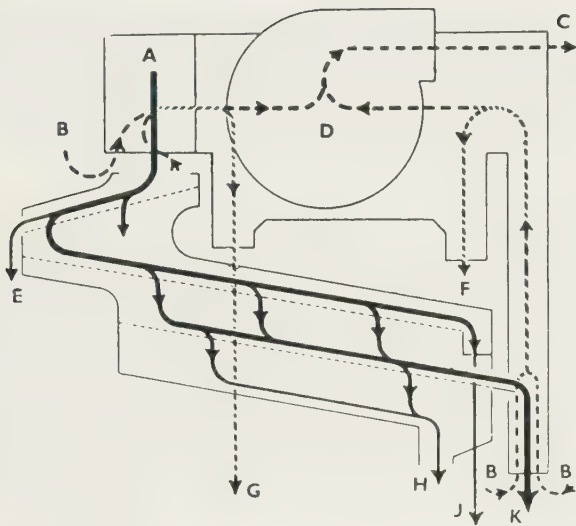


Fig. 17.2 Flow diagram of sieving grain cleaner with double aspiration. (Turner)
A Feed, B Air enters, C Dust and air exhausted to atmosphere or collector, D Fan draws air through grain at feed and delivery ends, E Rubble, F Liftings from delivery end, G Liftings from feed end, H Dirt and small seeds, J Large seeds, straws, etc., K Clean grain.

nation of sieves and aspiration. The essential difference between aspiration and winnowing is that winnowing employs a more or less horizontal blast, whereas an aspirating machine employs a controlled vertical air blast which operates in a confined space termed an aspirating leg. This permits a finer 'weighing' of the impurities in the airstream, and is more selective than winnowing. It also has the advantage that the escaping dust-laden air can be conveniently delivered by suitable trunking either directly out of the building, or to filter socks or a collecting cyclone. The sieves in such complex machines are automatically cleaned by brushes which move to and fro beneath them. In general, the greater the number of sieves designed into a machine, the greater the selectivity in grading it can achieve. The less complex machines, however, can often achieve comparable results if the seed is passed through twice or three times with changes of screen(s) between each operation.

In *rotary drum* graders the main component (Fig. 17.3) is a large-diameter rotary drum with a slightly inclined axis having interchangeable round-hole or slotted screens and a hopper-shaped base arranged to collect the produce

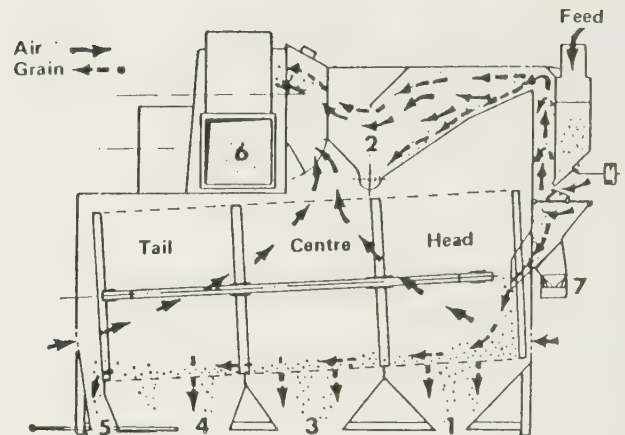


Fig. 17.3 Diagram showing grain and air flow through a three-screen rotary drum separator.
1 Small screenings, 2 Light impurities, 3 Smaller sample, clean grain, 4 Larger sample, 5 Rubble, 6 Fines to dust disposal, 7 Pre-cleaned grain outlet when drum is by-passed. (Law-Denis)

from the different aperture sizes. It is usually linked to an aspirating leg at the feed end and has an aspirating branch which removes light blowings from the grading areas. In a typical example suitable for large-farm use, two clean grain samples of slightly differing size are produced. A by-pass enables the aspirating leg to be used for pre-cleaning. Advantages of this type of machine are the absence of vibration and efficiency of use of the screen area.

Indented cylinders

These are used mainly for separation of impurities on the basis of their shape. The long, slightly inclined cylinders have indentations punched, cast or drilled on the inner surface. They are driven by gearing or belting, and as they revolve, grains which fit into the indentations are carried over and dropped into a chute inside the cylinder. Cylinders with various sizes of indentation will produce very accurately graded samples; for example, a sample of wheat, after being well cleaned in a winnower or an aspirating and sieving machine, may be passed through a cylinder with small indentations to pick out the small and broken grains and small weed seeds (e.g. 'goose-grass'). The grain may then be passed through a cylinder which picks out all the wheat except the very largest grains, and

leaves the seed free from large weed seeds (e.g. the wild onion). This type of machine is extensively used in Germany and Sweden. Its main disadvantages are that the rate of grading is slow, and the machine is expensive for individual farm use.

Pneumatic separators

Some simple cleaning and grading machines achieve separation by aspiration alone. The air blast in the aspirating leg is strong enough to 'weigh' the grain in the air-stream, the heavier fractions falling to the bottom, light fractions being taken off at an intermediate position, and the lightest materials being blown out with the air-stream. The factors governing separation are a combination of weight and air resistance. Such machines do not block, so are suitable as pre-cleaners, but cannot be expected to achieve such fine cleaning and grading as the more complex and expensive machines which employ a number of different separation processes.

Specific gravity table separators

The specific gravity table consists of an oscillating deck covered with fabric, woven wire or perforated metal, and with the upper end and one side adjustable for height. Air is blown up through the seed on the deck, at such a speed that the seed tends just to rise off the surface. The action of gravity tends to make material flow towards the lower corner, whereas the oscillation tends to take it to the higher side. Agitation of the mixture by the air flow causes the heavier seeds to sink to the bottom of the layer, while light seeds move to the top. The heavier seeds, being in contact with the deck, are conveyed towards the high side by the oscillation. The light seeds, because they are not in contact with the deck, flow by gravity towards the low corner. Such tables are used by seed merchants to effect a final sorting of certain types of seed and to remove inferior quality grains from milling wheat samples to improve the Hagberg number. A machine with throughput 5–10 tonnes/h can cost about £12000 to buy and install.

Wild oat separators

Hairy types of wild oats may be separated from grain by means of an inclined endless-belt machine. Separation is

based on the difference in adhesion characteristics, the rough wild oats being carried up the slope while the good grain rolls down. Hairless types of wild oats cannot be separated by such machines.

Operation of seed cleaners

The efficient operation of complicated cleaning and grading machines requires skill, for grain samples are so variable that a setting of the machine that is suitable for a particular sample is unlikely to be correct for the next sample dealt with. If the principles of operation are understood, however, the machine can be correctly adjusted with practice. The air blast can be controlled by adjustment of the fan blinds and sometimes by varying the speed of rotation. In many machines the slope, and the length and frequency of vibration of the sieves, can be varied; the sieves themselves are interchangeable, with a series of various sizes and shapes of mesh for different purposes.

Where it is necessary to clean and grade seed very thoroughly, advantage must be taken of many kinds of difference between the desired seed and the contaminant. In addition to the devices already mentioned, seed merchants often employ disc separators, which perform a function similar to that achieved by the indented cylinders already mentioned, velvet band 'dossors' for cleaning seeds such as clovers, and spiral separators for vetches. Flat seeds such as linseed may be separated by using special corrugated riddles with slots at the bottoms of the corrugations.

Grinding, kibbling and crushing machines

Grinding of stock feed is normal practice on most mixed farms. The objective is mainly to make the best use of home-grown crops, especially barley. Equipment available includes a wide range of grinders and mixers suitable for unattended operation. The grinding of grain has been practised since very early times, when a device resembling a pestle and mortar was employed in the production of meal for human consumption. The first mills were modifications of this device, in which grain was fed through an opening in a disc-shaped stone which was caused to rotate upon another. The gradual development of this type of mill during thousands of years has led to the evolution of the buhr-stone mill.

Table 17.1 Fineness of grinding for various types of stock

Type of stock	Machine	Crop	Size of screen		Description of meal
			(mm)	(in)	
Young chicks	Hammer or plate mill	Wheat,	2.4	$\frac{3}{32}$	Fine
Young pigs		barley	1.6	$\frac{1}{16}$	Fine
Adult poultry		and	3.2	$\frac{1}{8}$	Medium
Fattening pigs		maize	3.2	$\frac{1}{8}$	Medium
Cattle	Hammer or roller mill	Oats and barley	6.3	$\frac{1}{4}$	Coarse
Cattle, sheep	Hammer mill	Beans	9.6–12.7	$\frac{3}{8}$ $\frac{1}{2}$	Very coarse

The objects of grinding grain for stock are to increase digestibility or palatability, and to facilitate mixing with other constituents of the ration. Table 17.1 provides a general guide to methods of preparation and degree of grinding required for different classes of stock.

There is no advantage in fine grinding for cattle or sheep, and it should be remembered that the power requirement for very fine grinding is much greater than that for a medium grade.

One of the problems that face a farmer who is about to invest in food-grinding and mixing equipment is to decide

what size of plant is needed for the particular farm. As a general guide, dairy cows need about 750 kg (15 cwt) of concentrates per head per annum, bacon pigs 300 kg (6 cwt) and a laying hen 50 kg (1 cwt). There is usually a period of peak use in winter when all forms of livestock are needing the maximum amount of food, and the equipment should be chosen to meet this need. Other problems are the type or types of mill needed, and how to arrange the equipment to provide the most efficient operation.

Types of mill

Buhr-stone or plate mills

Buhr-stone mills are so termed because of the grooves (buhrs) which are cut on the grinding faces of the two disc-shaped stones. As one stone revolves upon the other, grain fed in at the centre passes towards the periphery, being gradually ground in the process. These mills can do excellent work, producing a fine meal without much heating, but they are somewhat cumbersome and require a powerful engine to drive them. They have been largely superseded on farms by chilled iron plate mills. The plate mill is a modification of the buhr-stone type. The plates are cast with corrugations which force the material outwards as in the buhr-stone type. The plates are made of a suitable iron to produce, by chilling, the maximum hardness with adequate toughness. They are easily interchangeable, and are usually made with corrugations on both sides so as to be reversible.

The fineness of grinding is controlled by the nature of the corrugations and by the clearance between the two plates, which are mounted on a horizontal shaft. The corn is fed from the hopper over a small oscillating screen which removes any large foreign bodies, and thence, by way of an auger-like device, to the centre of the inner plate. The outer plate is usually feather-keyed to the rotating shaft, and may be set at a variable distance from the fixed plate by means of a hand wheel. A spiral spring between the plates prevents them from touching when no grain is passing through, provided they are properly adjusted. A wooden break-pin, a strong spring, or a quick-release device is provided as a safety measure in case hard objects are fed into the mill. This type of mill performs coarse grinding or kibbling of wheat, barley and maize very efficiently. A high-speed type incorporates

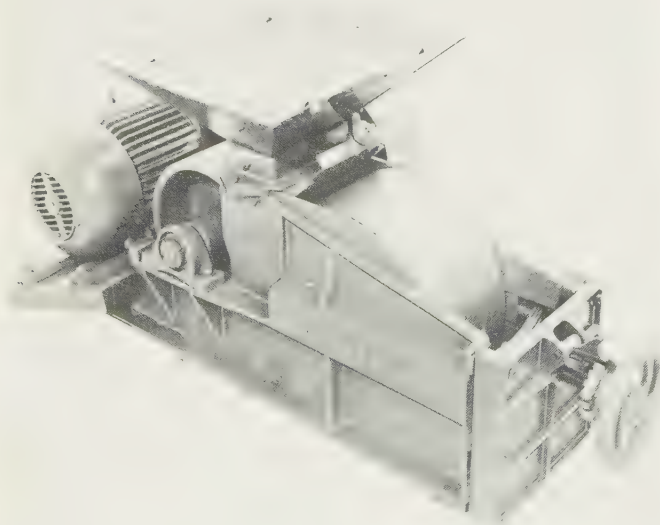


Fig. 17.4 Roller crusher with hinge-mounted motor. (Bentall Group)

a fan for meal delivery and can produce a medium meal from moist grain.

Roller crushers

Crushing mills consist essentially of two cylindrical rollers between which the grain is crushed. Grain is generally delivered to the crushing rollers by a small fluted feed roller, through a variable slide in the bottom of the hopper. When the rollers are of unequal sizes, the larger one is keyed to the main driving shaft (which also carries the grinding plates in a combination mill) and is carried in fixed anti-friction bearings. The smaller roller, which is usually ungeared, is carried in sliding bearings, and can be pressed against the driven roller, through the medium of strong spiral springs, by the operation of a hand wheel. The spring mounting provides a safety device in case hard foreign bodies are introduced between the rollers. Effectiveness of a roller crusher depends on securing an even flow of single grains between the rollers, and this can be difficult, especially with very hard grain, where the rollers are of small diameter. It is therefore advisable to look for a machine with rollers of fairly large diameter, even on crushers of small capacity.

The object of crushing is to break the husk and allow the digestive juices of stock to act on the flour, without producing a dusty, floury product.

High-speed corrugated roller mills may be used for crushing either dry or high-moisture grain. The case-hardened corrugations tend to give a cracking effect rather than simply flattening the grains to a disc shape. The rollers are normally both driven, and are geared to run at the same peripheral speed. The gap between the rollers is adjustable by means of a spring-loaded mechanism designed to ensure an equal gap at both ends of long rollers.

Ease and effectiveness of operation of any type of crusher, especially with barley, is dependent on having the grain at a suitable moisture content. Barley should preferably be at about 18% moisture content, and if the grain has been stored very dry it may be worthwhile to add some water before crushing. One way of doing this is to trickle water on to the grain as it passes through an auger or other conveyor on its way to a hopper in which it can be stored for a short time (about 12–24 hours). Only about 3–4% can be added at a time to barley, and less to most other cereals.

One method of adding moisture is to generate steam and treat the grain with a controlled application of steam immediately before crushing. Use of steaming equipment has the advantage of avoiding the necessity of preparing a bulk of grain each day in preparation for the next day's crushing. Apart from this, the main advantage is convenience of control. The amount of steam applied is normally insufficient to cook the grain. It could, however, in some cases have a useful partial sterilising effect.

One of the main advantages of moistening grain before feeding is reduction of dust, which can cause respiratory troubles in livestock. One manufacturer offers a device for adding water to meal after the ration has been ground and mixed. The meal passes through a small horizontal cylinder with a central shaft having spirally arranged fingers. The water is added via a hose and an adjustable nozzle; and the fingers perform the dual function of stirring and propelling the meal through the cylinder. The need for a fairly high moisture content for crushing raises the question of storing the grain at a high moisture level – a subject discussed in Chapter 18.

The approximate capacities of various sizes of plate and crushing mills are given in Tables 17.2 and 17.3.

Table 17.2 Approximate power requirements and capacities of plate mills

Power		Approx. capacity per hour, dry grain			
		Medium grinding		Kibbling	
kW	hp	kg	cwt	kg	cwt
1.5	2	125	2½	300	6
3.0	4	250	5	600	12
6.0	8	500	10	1200	24
9.0	12	750	15	1800	36

Table 17.3 Approximate capacities of roller crushing mills

Power		Approx. capacity per hour	
kW	hp	kg	cwt
2.2	3	250–500	5–10
3.7	5	500–800	10–16
5.6	7½	800–1200	16–24
7.5	10	1100–1600	22–32

A good method of operation is to mount the crusher above an inclined chain and slat-mixer, but where this is impossible a slow-running auger or a small blower can sometimes be used to transfer the product to an elevated bin.

Hammer mills

The mill consists of a number of steel hammers which rotate at high speed on a shaft or rotor set in a strong housing. As the material is fed from the feed hopper into the mill, the hammers strike it with great force and rapidly pulverise it. At a point close to the periphery of the hammers is a screen, and as the material is reduced in size it passes through this screen. It is then usually elevated by means of a fan to a collecting cyclone, where it can be bagged off. The fineness of grinding is regulated by the use of screens of different mesh. Hammer mills are simple in construction and cost little for the replacement of parts.

One popular type is a small mill that requires only 2.25 kW (3 hp). With a suitable layout of feed bins and meal bins it is possible with such a machine to secure fully automatic operation. A time switch may be set to start the mill at a predetermined time at night, when a cheap rate for power is available; grinding will continue until the bin is empty, when an automatic cut-out switches off the motor. The corn to be ground falls by gravity from a bin above the mill, while the meal is blown into a storage bin. Such an outfit has been found capable of dealing with 3–4 tons of mixed grain per week when used part-time in the way outlined above. Automatic mills of 3.7 kW (5 hp) can do all that is required on many medium-sized farms.

Table 17.4 shows typical performances of mills of various sizes.

Milling rate falls rapidly as the moisture content of the grain is increased and this effect is particularly marked with oats.

Fig. 17.5 illustrates the method of operation and automatic control employed on a typical small mill. So long as grain flows from the hopper above the mill, the diaphragm of the automatic switch is depressed, and the mill continues to run. As soon as the grain hopper is empty, a spring causes the diaphragm to move upwards, and this switches off the mill. In its passage from the hopper to the grinding chamber, the grain is sucked over a weir,

Table 17.4 Approximate outputs from hammer mills

<i>Power</i>		<i>Output per hour with barley at 15% m.c. through 4 mm (medium) screen</i>	
<i>kW</i>	<i>hp</i>	<i>kg</i>	<i>cwt</i>
2.2	3	100	2
3.7	5	200	4
5.6	7½	350	7
7.5	10	450	9
15.0	20	800	16
30.0	40	1600	32

Effect of crop and screen size 3.7 kW (5 hp) mill

<i>Crop</i>	<i>Output (kg/hour)</i>		
	<i>Coarse</i>	<i>Medium</i>	<i>Fine</i>
Wheat, maize, beans	350	200	125
Barley	350	200	100
Oats	350	150	75

Effect of moisture content 3.7 kW (5 hp) mill, barley 2.4 mm ($\frac{3}{32}$ in) screen

<i>Moisture content (%)</i>	<i>Output (kg/hour)</i>
13	200
15	175
17	150
19	125

heavy impurities which might damage the mill being retained at the bottom of the hopper.

When used at full capacity on coarse grinding, a 2.25 kW (3 hp) mill can deal with 5–6 tons of feeding-stuffs weekly.

'Tub' grinders

Adoption of 'complete diet' feeding and use of the mixer wagons involved in the practice has led to increased interest in making the best use of cereal straw, provided that the straw can be effectively incorporated into rations and utilised by cattle. Grinding of cereal straw by means of ordinary hammer mills is not easily effected because of the difficulty of arranging a uniform feed. Tub grinders are designed to overcome the difficulty by provision of a hydraulically driven tub which has its speed of rotation

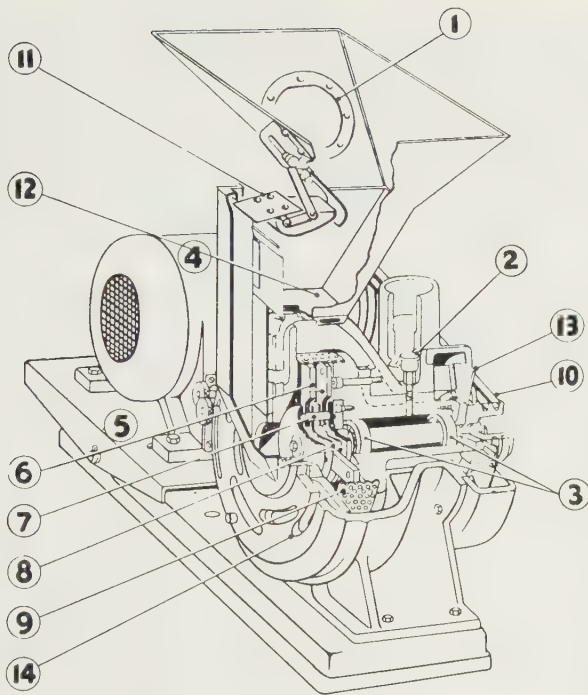


Fig. 17.5 Interior view of automatic hammer mill. (*Christy Hunt Engineering*)

1 Diaphragm cut-out switch, 2 Stauffer lubricator, 3 Ball and roller bearings, 4 Motor, 5 Motor platform on hinge pin, 6 Hammers, 7 Hammer retaining pin, 8 Rotor plates, 9 Perforated steel screen, 10 Vee belts (2), 11 Feed control flap, 12 Stone and iron trap, 13 Fan, 14 Extra air intakes.

automatically controlled by a governor. Speed of rotation and of feed are reduced if the hammer type mill slows down and tends to stall. A fairly coarse grinding is normally aimed at, and the product is usually delivered into a store ready for handling into a mixer wagon. Such grinders are specially suited to receiving big round bales, which can easily and quickly be handled into it by tractor loader.

Meal bins

Low-powered mills employ only a small fan, and a satisfactory method of separating the meal from the air is to

Fig. 17.7 Tub grinder arranged to deliver direct to complete-diet feeder. (*Farmhand*)

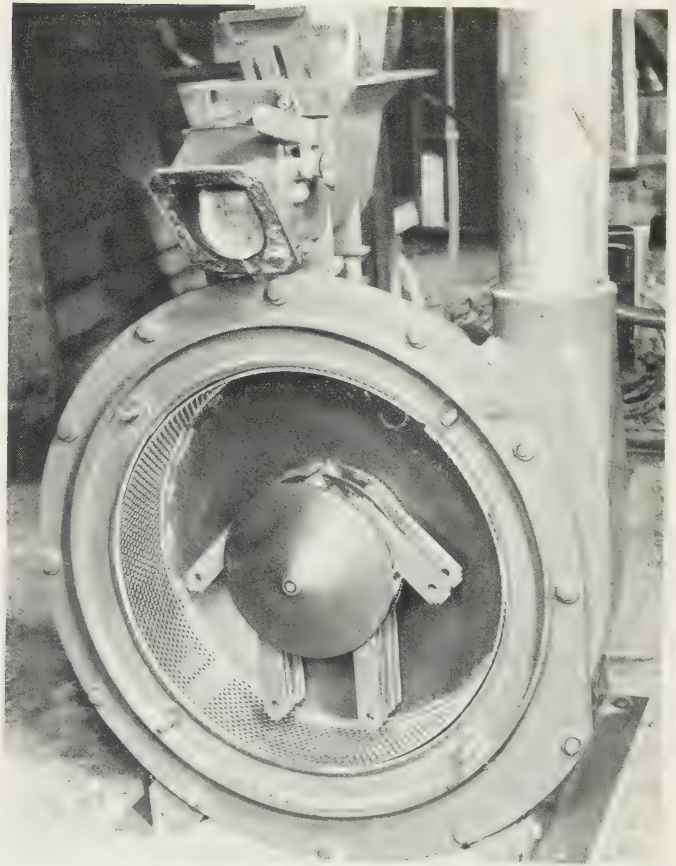


Fig. 17.6 Hammer mill with cover removed showing hammers and screen. (*Bentall Group*)



blow it into bins fitted with filter-cloth tops, or direct to a mixer fitted with a filter stocking. The filter cloth is fitted loose, so that it balloons upwards when the mill operates. When blowing stops, the filter cloth falls back and jolts off much of the adhering meal. It is necessary occasionally to beat the distended surface of the filter with a carpet beater or stick to assist the cleaning process. The area of filter cloth needed depends on the size of mill. As a general guide, about 10 ft² of filter cloth is needed per hp of the motor (1.25 m²/kW).

When larger mills are employed, use of a cyclone is essential, but such mills can be made semi-automatic in operation by delivering the meal from the cyclone to storage bins. It is almost impossible to construct simple meal storage bins that do not give some trouble with sacking-off. Even if a very steep angle to the sacking-off spout is employed, the meal will bridge when the bin is full. One satisfactory form of construction is to have parallel sides and a fairly flat bottom leading to a large vertical bagging-off slide which permits use of a small rake to pull the meal forward. Bins should not be more than about 0.9 m (3 ft) wide and 1.4 m (4.5 ft) from front to back. To prevent meal lodging hard against the slide it is advisable to construct a deflecting board above it. The top of the deflector should be about 150 mm (6 in) above the top of the slide, and the board should slope inwards at an angle of 45°. It is advisable to provide a large inspection panel near the top of the bin. The size and number of meal bins needed naturally depends on policy regarding mixing. As a general guide to capacities required, the following figures may be used: cattle rations are usually light, and weigh about 350 kg per m³ (22 lb per ft³); pig rations average about 450 kg per m³ (28 lb per ft³).

For handling large quantities of meal one of the best methods is to use a steeply hopper-bottomed bin with an auger running inside the bin, parallel with the slope of the bottom. The agitation caused by the auger is normally adequate to deal with even finely ground meals. For small quantities of meal there is everything to be said in favour of blowing to the mixer, a method referred to again later.

Choice of a mill

For medium or coarse grinding or cracking of maize, wheat or barley, the plate mill is satisfactory; it is less

efficient for fine grinding. For the fine grinding of these grains, and especially of oats, the hammer mill is most efficient. On farms where a large head of stock is kept it may be economic to use a plate mill, a hammer mill and a crushing mill to meet the variable requirements of sheep, beef and dairy cattle, poultry and pigs. On smaller farms either a combination of plate and crushing mill or a small automatic hammer mill may be the most suitable equipment.

Where a large farm needs to grind and mix appreciably more than 1 ton daily, it will often be better to choose two independent 3.7 kW (5 hp) automatic hammer mills, rather than one large machine. The smaller machines are usually cheaper and at least as efficient, and they provide a flexibility that is often advantageous.

'Mix-milling'

A technique which is very suitable for large-scale feed preparation on individual farms may be described as 'mix-

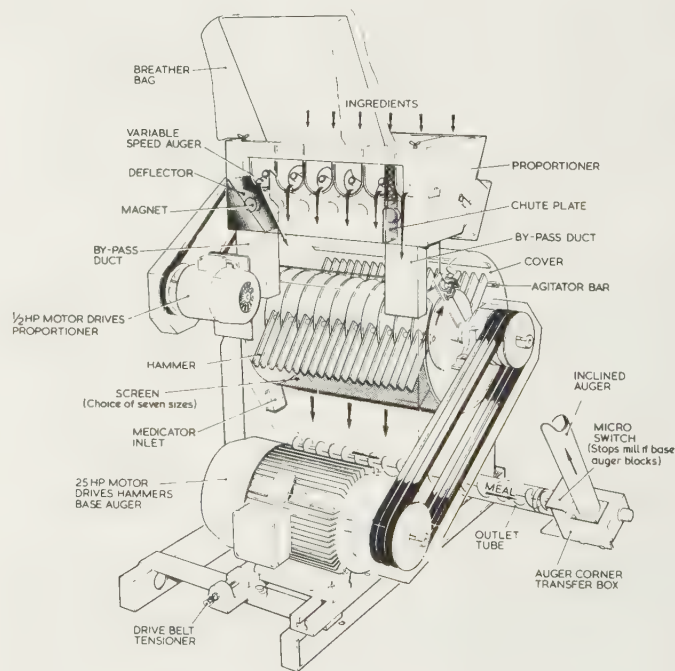


Fig. 17.8 Medium-powered proportioner mill with by-pass duct, and inlet to facilitate use of separate medicator unit. (Econ-Group)

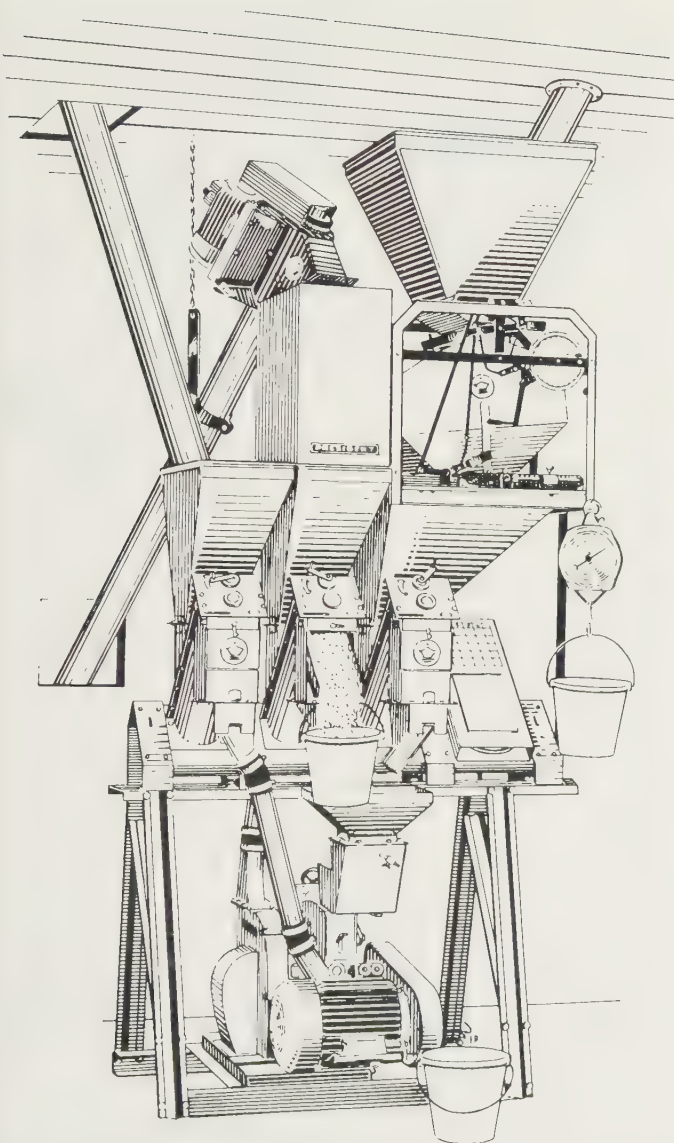


Fig. 17.9 Mix-mill arrangement for three components. (*Brice-Baker/President*)

Cereal on right is independently weighed by oscillating weigher which can be set to control batch size. Illustration shows checking of flow rate of centre component. Left component is set to by-pass the mill.

milling'. The method of operation is very simple. Each of up to six components of a mix is stored in such a way that it can finally be fed by gravity or by auger to the mill. A common arrangement is to have above the mill a nest of



Fig. 17.10 Compact vertical-auger mill-mix combination. (*Rowlands Engineering (Aylsham) Ltd*)

hoppers which can be filled by the usual type of conveying system.

The mix-mill itself incorporates 4–6 variable-speed augers, each of which can be independently controlled by adjusting a dial. A typical arrangement is to have barley, wheat, beans etc., fed into the mill in the desired proportions, and to use one channel for adding a pre-mixed 'balancer' meal. The latter, which may contain vitamins, can be arranged to bypass the mill chamber to avoid deterioration by heating.

An automatic control will stop the mill as soon as any ingredient runs out.

This type of arrangement is suitable for feeding directly into an auger conveying system for delivery to poultry houses, etc. Thus, the whole business of feed preparation and transferring feed to bulk hoppers in the stock buildings may be carried out by push-button controls.

Distribution to the stock buildings may be by means of suitable augers or chain-and-flight conveyors; another

method is pneumatic conveying using a medium-pressure small-bore conveying system. For the latter, which does not normally require a cyclone, pressure is up to 1.4 bar (20 psi) compared with a maximum of about 0.2 bar (3 psi) for the low-pressure system. In the medium-pressure system the feed : air ratio is 10–20 : 1 by weight, compared with 3 : 1 for the normal low-pressure system.

Feed-mixing machines

The mixing of feedstuffs to form a uniform ration is a regular need on large stock farms. The mixer usually consists of a steel cylinder tapering to a conical hopper at the bottom. The mixing is performed by a large vertical auger which revolves continuously, carrying material from the bottom of the hopper and sprinkling it over the surface. Machines are usually directly driven by V-belts, from a motor mounted on the top of the machine, with its shaft vertical.

There are two main types of vertical mixer; those fed from the top and those fed from a hopper at or near floor level. As a general rule, the latter run at a higher speed and require more power than the top-fed types, but they are usually more convenient to install and to operate, and on this account have become very widely used. The top-feed type may, however, be suitable where a good two-storey building already exists. It can, of course, be fed from the ground floor by means of a bucket elevator if necessary, but this involves a considerable extra cost. The bottom-fed type may be free-standing, with its hopper about 460 mm (18 in) above floor level. Alternatively, on some makes, the hopper may be situated below floor level if this is desired. Power required for a $\frac{1}{2}$ -ton mixer of this type is 2.2–3.7 kW (3 to 5 hp). The mixer should usually be run while it is being filled and for a few minutes after filling is complete. With all the materials handy one man can complete the mixing and bagging of $\frac{1}{2}$ ton of rations in 15 to 20 min.

It is often advantageous to blow meal directly from a hammer mill into the mixer. The meal should enter through a tangentially located inlet, and there must be a filter sock of adequate size in the top, or an arrangement for recirculating the air through the mill.

When the mixer is used in this way it is necessary to be able to start up the motor under load, and both the mixer and the motor should be chosen with this need in view.

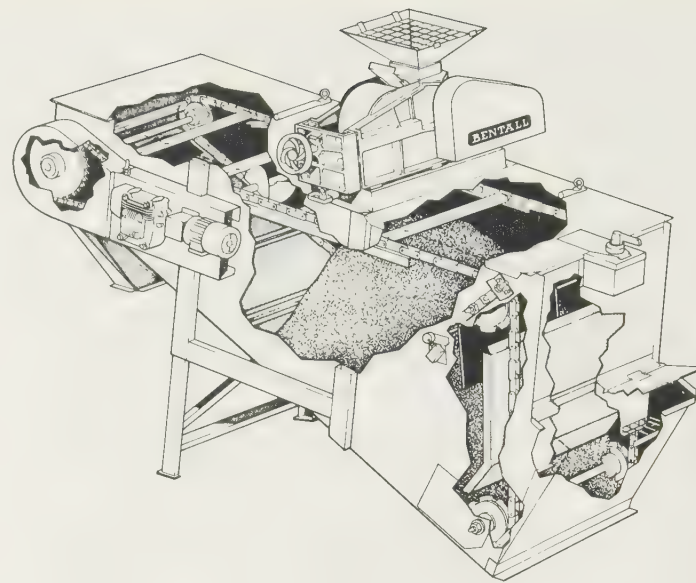


Fig. 17.11 Chain and slat inclined conveyor mixer with roller crusher mounted above. Concentrates are added via hopper on right, delivery is via chute at left, above agitator. (Bentall Group)

A type of mixer that tests have shown to be effective consists of an endless-chain-and-slat conveyor which draws the meal up the inclined base of a wedge-shaped container, and allows it to cascade back towards the bottom of the slope (Fig. 17.11).

Unfortunately there have been few official tests of the evenness of mix of the various types of machine, but such results as are available indicate that most of the machines on the market give a better mix than good hand methods.

Table 17.5 shows the nominal capacities, range of gross volume and power required for typical bottom-fed mixers of conical shape. Such mixers usually operate at speeds in the region of 800–900 rpm and require more power for a given capacity than top-feed machines, which usually operate at only 150–200 rpm.

The practical operating capacity of many mixers is less than that indicated by the nominal size. Gross capacity needs to be about 10% more than the space occupied by the quantities to be mixed.

Table 17.5 Capacities and power requirements of typical vertical-auger mixers

Batch size (tons)	Min. gross capacity for effective mixing				Power required (kW) (hp)	
	Low-density ration* (m ³)	High-density ration* (ft ³)	Low-density ration† (m ³)	High-density ration† (ft ³)		
$\frac{1}{2}$	1.6	56	1.2	44	2.2–3	3–4
1	3.2	112	2.5	88	3.0–3.7	4–5
$1\frac{1}{2}$	4.8	168	3.6	132	3.7–5.6	5–7 $\frac{1}{2}$
2	6.4	224	5.0	176	5.6–7.5	7 $\frac{1}{2}$ –10

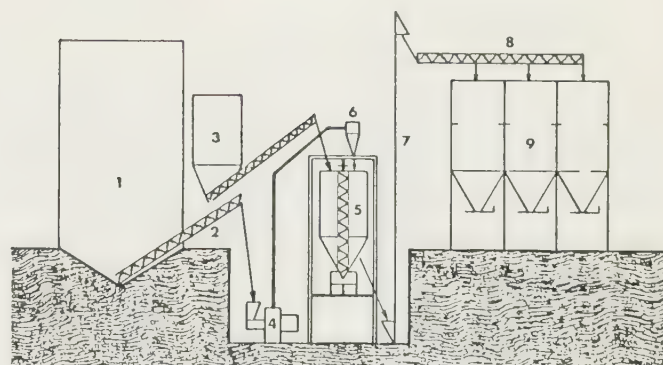
* 22 lb/ft³ (350 kg/m³).† 28 lb/ft³ (450 kg/m³).

Fig. 17.12 Flow diagram of automated batch mill-mix installation using an electronic mixer weigher. 1 Grain bin with variable-output auger 2 to mill 4 with pneumatic delivery to mixer weigher 5 via cyclone 6. Additives bin 3 delivers direct to mixer. Bucket elevator 7 delivers to storage bins 9 via horizontal auger 8. (Law-Denis)

Weighing hoppers and mixer weighers

Useful aids to the preparation of rations on farms include weighing hoppers mounted above mixers, and electronic mixer-weighers which weigh the ingredients in the mixer itself.

A good example of the simpler *weigh hopper* is a steelyard type which can easily be accommodated on a weigh frame above an inclined endless-chain type mixer with a grinding mill, roller crusher unit, or both, mounted above it (e.g. Alvan Blanch). A micro-switch attached to the steelyard beam can easily be set to switch off supply of the main ingredient when the quantity needed for a batch is reached.

A suitable electronic *mixer weigher* can provide the nucleus for an automated medium-size farm-scale batch milling and mixing installation capable of following repeatable programmes. The basic need is suspension of the mixer casing by strain gauge with flexible sleeves on a purpose-designed weigh frame. A control panel can accommodate the required number of constituents for typical stock-feed needs, employing an arrangement as indicated in Fig. 17.12.

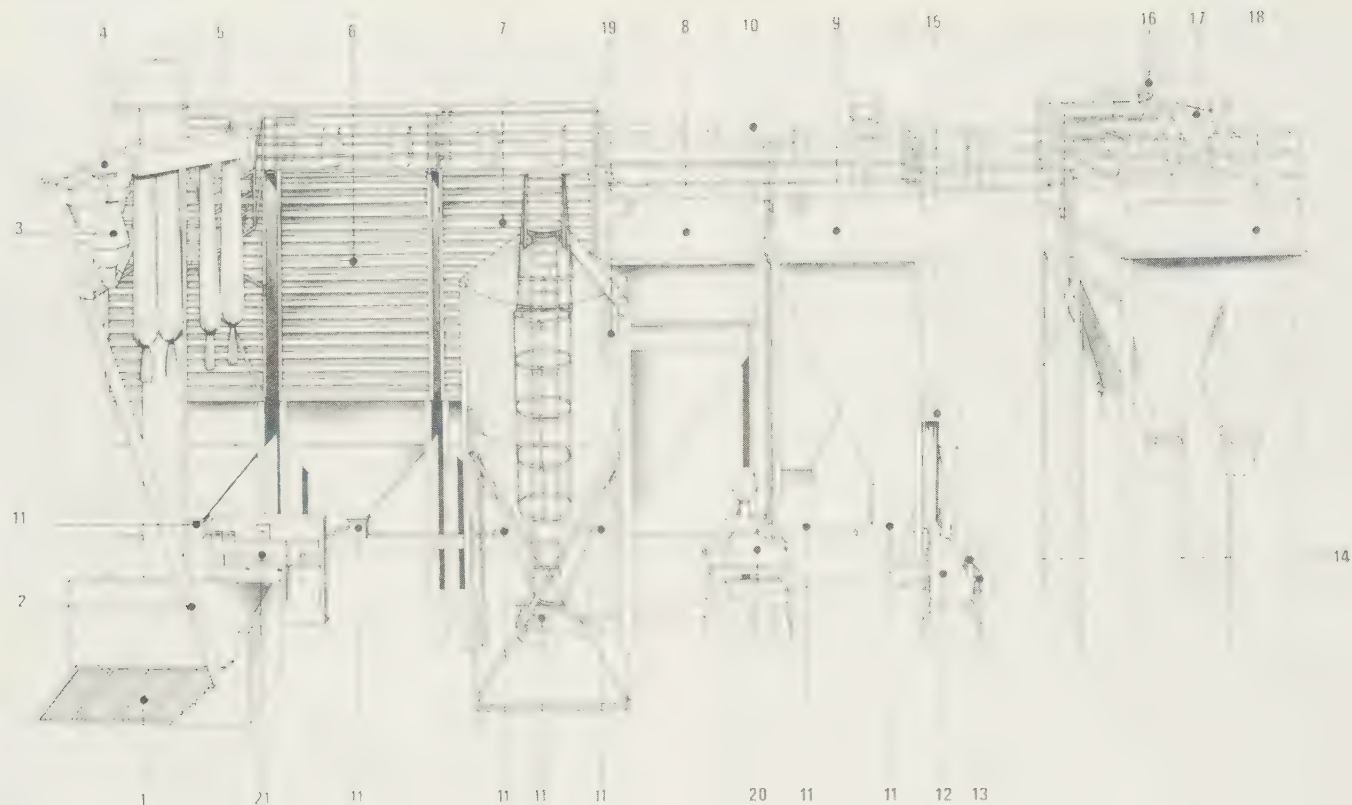
Mill-mix systems with proportioners at supply bins: An adaptable mill-mix system with easy variation of feed ingredients and of aspects such as scale of operations employs simple short chain-and-flight proportioners to meter inputs of grains, cereal by-product meals and concentrates, into one or more main chain-and-flight conveyors. A fairly complex arrangement capable of satisfying

a need for a wide variety of rations is illustrated in Fig. 17.13. Each proportioner comprising a short length of chain-and-flight operates above a dead plate and drops its component, metered by a control slide with graduated scale, into the bottom run of the main conveyor. The drive for several proportioners is provided by the top (return) runs of the main conveyors.

Addition of molasses to mix

A simple arrangement for batch mixing involves spraying a pre-heated measured quantity into the mixer by means of air pressure. The 45 or 90 l (10 or 20 gal) pressure tank is surrounded by an electrically heated water jacket. After the molasses reaches a suitable temperature a small compressor is started, and when an operating pressure of about 1.4 bar (20 psi) is reached the liquid is sprayed into the mixer through a simple fan jet (Alvan Blanch).

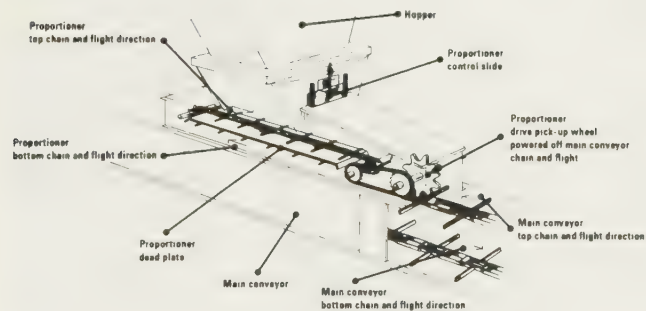
Where thick wet mixtures have to be prepared a horizontal mixer may be used. These usually have a U-shaped trough with a mechanical agitator running along the bottom. Horizontal mixers are usually filled from above and discharged through a valve in the bottom of the trough. Capacities of wet-mash mixers range from 50 kg (1 cwt) to 1500 kg (1 $\frac{1}{2}$ tons).



(a)

Fig. 17.13 Large farm-scale fully mechanised mill-mix system with chain-and-flight proportioners. (*Rowlands*)

(a) General arrangement showing 6 proportioners driven by main conveyor, and additional roller mill-mix system. Rations are stored in elevated bulk hoppers to facilitate distribution to feed points. 1 Grain intake pit, 2 Return pipe, 3 Pre-cleaner, 4 Dust cyclone and filters, 5,6,7,8,9 Square hoppers for maize, barley, wheat, wheat feed and concentrate, 10 Cross conveyor 11 Proportioners, 12 Mixing auger, 13 Medicator, 14 Hammer mill, 15 Cyclone and filter, 16 Meal elevating auger, 17 Left and right hand cross conveyor, 18 Outloading hoppers, 19 Concentrate hopper, 20 Roller mill, 21 Control panel.



(b)

(b) Proportioner unit showing drive, with speed variation by change of chain drive sprockets, and fine adjustment by control slide (*Rowlands Engineering (Aylsham) Ltd*)

Liquid feed mixing

The introduction of pipeline pig feeding has brought renewed interest in mixing rations in liquid form. In most liquid pig-feeding installations, arrangements are made

for a very thorough mixing before pumping to the pipeline begins. This makes it practicable to carry out the whole of the mixing operation in the liquid feed mixer, and so eliminates the need for a dry-mixing operation. Mixing is normally carried out by a combination of brisk mechanical

stirring and recirculation. In some automatic liquid feeders metering of the ingredients is on a continuous basis, and only a small quantity of feed is pre-mixed at any one time (see Chapter 19).

A vortex mixer developed by Silsoe Research Institute has the liquids, which may include whey or skim milk as well as water, injected tangentially near the base of an open-top small-diameter cylinder, while the meal is dropped continuously through a tube into the centre of the vortex. The feed pump draws off the mix from a pipe centrally located at the bottom of the cylinder. Control of the liquid: solid ratio can be maintained by use of a flow-control valve and a continuous meal weigher.

Planning feed preparation installations

The provision by manufacturers of combined milling and mixing plants, complete with simple automatic control gear, makes installation of such small plants easy. Nevertheless, it is advisable to site the equipment carefully, so as to minimise handling of both the raw materials and the finished ration. Where a crusher is used it may be linked with a meal store or mixer by means of a pneumatic conveyor, a bucket elevator or an auger. On a small scale it is usually best with either a mill or a crusher to meter the grain before processing, and to deliver the metered batch directly to the mixer. Volumetric metering is usually adequate for small plants.

With larger installations there is much to be said for bulk handling, especially as this permits the introduction of effective automatic controls, which can save a great deal of labour.

In modern installations the whole operation can be controlled by means of dials on which the required quantities of different ingredients can be pre-set on a central console. Such equipment can be well worthwhile where quantities in the region of 50 tons per week are handled.

Cubing machines

When meal mixtures of a moisture content that is normal for home-mixed rations are subjected to high pressure, the mixture becomes hot, the individual particles stick together, and the hard lumps that are formed take on the shape of the container in which the meal is compressed.

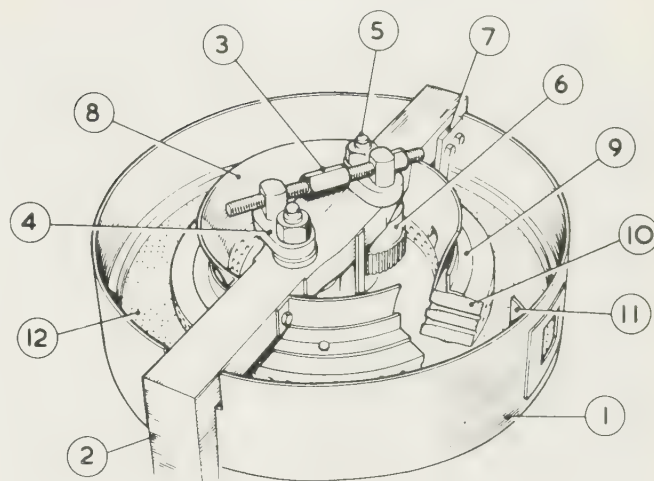


Fig. 17.14 Cuber with two interconnected fluted rollers and rotating die ring. (Christy and Norris)

1 Stationary plate, 2 Bridge, 3 Adjusting screw, 4 Adjusting links, 5 Roller spindles, 6 Rollers, 7 Knife, 8 Meal hopper, 9 Retaining strip, 10 Die, 11 Deflector, 12 Sifting plate.

The hardness and resistance to crumbling of the product depends on several factors, such as the composition of the mixture, the fineness of grinding, the moisture content and the pressure to which the mixture is subjected. Cubing machines are usually designed to produce short cylindrical sticks of various sizes, the larger sizes being called 'cubes' and the smaller ones 'pellets'. The large cubing machines used in mills where compounding is done on a commercial basis often use steam and molasses to assist the cubing operation, but most farm-size cubers can work without the addition of either steam or molasses, though addition of a binding material helps to make a stable cube.

The method of operation typical of most cubing machines is illustrated by Figs 17.14 and 17.15. The meal mixture passes from a vibrator feed into a cylindrical compartment with walls consisting of a heavy revolving die ring. The die ring has a large number of radially located holes which are tapered from the inside to the outside of the ring. The die ring is driven through reduction gearing by the power unit, and as it rotates, meal is directed by suitably shaped ploughs to the points where the inside of the die ring meets the circumference of two or more rollers, which are free to rotate on their supporting shafts. The rollers are usually fluted, but may be plain on

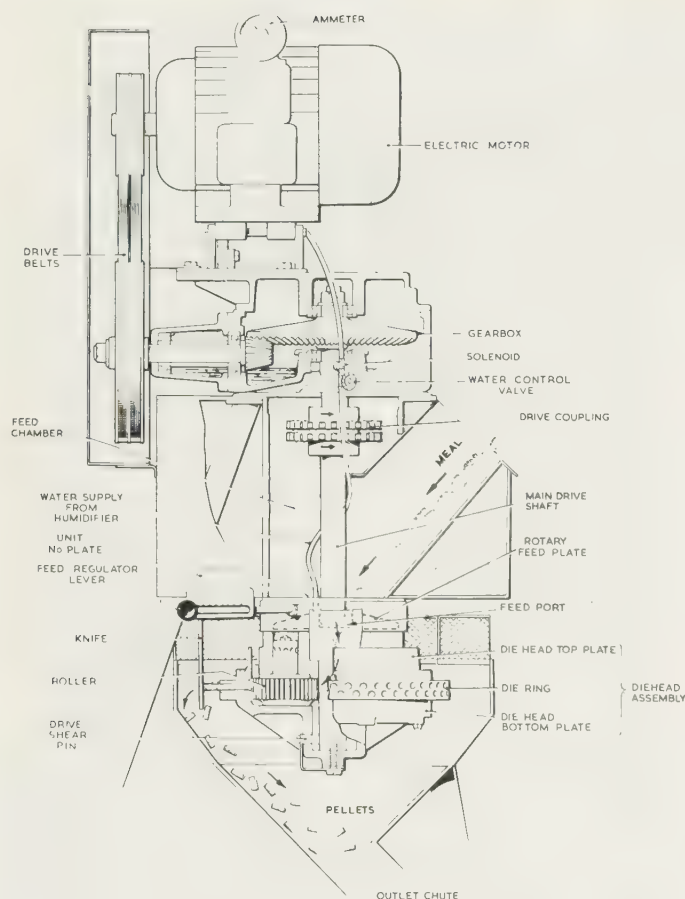


Fig. 17.15 General layout of farm pelleting press. (*Econ-Group*)

large industrial machines. The meal is forced into the die by the roller, and it emerges from the outside of the ring as solid sticks of meal. These sticks come into contact with a stationary knife which cuts them into suitable lengths, thus completing the formation of the typical cylindrical 'cubes'.

The cubes usually pass on to a perforated sifting tray which helps to remove any small fragments. Cubes or pellets produced in small farm machines may be bagged off immediately in hessian bags that are at first stacked to allow some circulation of air. They should not be stored in bulk without cooling.

Typical cubes are 10 mm ($\frac{3}{8}$ in) or 12 mm ($\frac{1}{2}$ in) in diameter, while pellets may be of 3 mm ($\frac{1}{8}$ in) in diameter. In general, the smaller the diameter, the lower is the

output of a given machine, so the larger sizes are usual for adult cattle, and the smallest size only for poultry.

Root cutting machines

The ease with which heavy crops of roots can now be grown and mechanically harvested, coupled with high cereal prices, has resulted in the development of economic mechanised root-feeding systems, some areas of application being Scotland, Wales and North-East England.

Disc-type cutters usually have a V-shaped hopper, one side of which is formed by the cutting disc. The cutter is a steel disc in which are a number of openings, surrounded by sharp-edged lips that face in the direction of rotation. Rotation of the disc forces the projecting lips against the roots, and slices are cut off and pass through the openings to the back of the disc. Cleaning the roots before slicing is often essential: rotary cleaners similar to those used on sugar beet cleaner-loaders may be employed. Most stationary machines incorporate or can be fitted with a cleaner consisting of a rotating wire cage with spiral cleaning bars. The whole roots are fed into the upper end of the cage, and the dirt is scraped off them as they pass slowly down to the cutter (see also Chapter 12 – complete diet feeders).

Mobile root feeders

Modern equipment includes a tractor-operated root-feeding trailer (e.g. Boswell) with a body capable of holding about 2 tons of roots. A pto driven cutting drum is built into the front of the chassis, and the sliced roots are fed into a cross auger for delivery into the mangers. The trailer body is hinged at the front, and is tipped by a hydraulic ram, thus ensuring a constant flow of roots to the cutting drum. Where practicable, stones should be separated by use of a cleaning drum before processing.

Straw processing for stock feed

The main constituent of straw is cellulose, a carbohydrate which can be utilised by ruminants provided that the indigestible lining that encloses it can be dissolved.

Danish research on treatment with anhydrous ammonia led to the development of practical systems of producing a palatable feed with greatly improved cellulose digest-



Fig. 17.16 Ammonia straw treatment oven of four big bales capacity being loaded. Anhydrous ammonia tank is on right (*Straw Feed Services*)

ibility, plus the benefit that nitrogen compounds produced by the chemical action can be utilised by ruminants as a crude protein substitute. The 'oven' system introduced a standard treatment which is applicable to either conventional or big bales and operates on a 24-hour cycle, with full automatic control after a pre-set quantity of ammonia is transferred from the NH_3 pressure tank into the loaded and sealed oven (e.g. FMA; SFS). In a typical cycle, 3% NH_3 by weight is delivered into the oven, and the chemical reaction produces a substantial amount of heat. Additional electrical heating is supplied, and automatic control with fan circulation provides a treatment temperature of 95°C for 14–15 hours. This is followed by 4 hours 'stand-still'

and then about 4 hours ventilation before the doors are opened.

Common batch sizes range from 2–8 big bales or 40–60 small. Bale handling is usually by front loader; a telescopic-boom handler has obvious advantages. Traces of ammonia are present when the bales are first removed. Refinements offered include extraction for later re-use of removable NH_3 after the main treatment period (FMA). In an oven of octagonal section, a door at both ends allows 'push-through' handling. Costs can be fairly accurately predicted and are not negligible; the benefits depend on good stock husbandry; a mix with other bulk feeds is often sound. Many users are happy to be able to release land for production of cash crops by cutting down forage crop area. Other methods of treatment include (a) use of very large insulated containers designed for a 10–14 day treatment period without added electrical heat; (b) a contract system based on a small tractor rear-mounted gas tank and injection of one big round bale at a time through hollow spikes which form the front-mounted handler. The bales are then pushed into a large-diameter polythene tube for storage (SFS).

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Crop Drying and Grain Storage Equipment

Principles of crop drying

Although moisture may be extracted from various substances in a variety of ways, the method universally adopted in farm crop driers is 'vaporisation', with removal of the moisture in a stream of drying air. Vaporisation does not necessarily involve boiling the water and converting it to steam; in fact, many farm driers operate at temperatures well below boiling point, and some at atmospheric temperature. The picking up of moisture by a stream of drying air depends on the fact that the moisture in the crop tends to come into a state of equilibrium with the drying air. The power of the air to dry the crop depends on the difference between the amount of water vapour it already contains and the amount that it can hold if saturated. The amount of water that a given volume of air can carry increases rapidly with temperature. For example, the amounts held by a given volume of saturated air at 0°C, (32°F), 38°C (100°F) and 95°C (200°F) are in the proportion 1 : 10 : 100. It may be seen, therefore, that if there is a given amount of water to be removed from a material by an air-stream, this may be achieved either by a small volume of air leaving the drier at high temperature, or by a larger volume exhausted at a lower temperature. It would, of course, be useless merely to increase the temperature of air used for drying if this air remained saturated with water vapour. Heating a given volume of atmospheric air which contains a definite amount of water vapour in fact reduces its relative humidity – i.e. the ratio of the actual amount of water vapour that it contains to the amount that it could hold at the given temperature if the air were saturated. Heating the drying air is, therefore, a common method of speeding up crop drying processes, and incidentally of increasing thermal efficiency. Drying temperatures employed are usually as high as they can safely be, without causing

damage to the material being dried, or leading to inefficient operation in other ways.

The germination of grain is easily ruined by use of too high drying temperatures, while burning of the most valuable parts of the crop may occur if too high temperatures are employed in grass drying. Methods of reducing the relative humidity of air without increasing its temperature include drying it by chemical means – a method once tried in connection with the drying of grain in ventilated bins.

Crop drying processes cannot normally be carried out at unlimited speed. For example, in grass drying, the moisture in the leaf readily passes out through the innumerable stomata in the leaf surfaces, but moisture in the stemmy parts of the crop takes a long time to move to the surface, where extraction can take place. Similarly, surface moisture on grain may be removed in seconds, whereas moisture from the middle of the berry may take minutes or even hours to diffuse to the surface. It is for reasons of this kind, as well as on account of damage to the crop, that drying must proceed at a moderate speed in most types of drier, and that grass bruising and similar processes which assist rapid drying are of commercial interest.

Most grass and grain driers employ some kind of furnace for heating air, and a fan for blowing it through the drier. Both green crops and grain are usually dried by 'direct' heating methods, in which hot gases from a furnace, and a controlled volume of cold air, are mixed together and passed through the crop. In grain driers, temperature of the mixture may be controlled at from below 38°C up to 105°C (100°F–229°F); in low-temperature grass driers, temperatures of 105–150°C (220° to 300°F) are common; while in high-temperature grass driers initial temperatures may be well over 538°C (1000°F). In the case of a continuous grain drier, drying may take an hour or more, where-

as with high-temperature grass driers the light fractions may be completely dried in a few seconds. At the other extreme, grain at the top of a ventilated silo may take 10–14 days to dry.

When the capacities of various types and makes of drier are compared it is important to specify working conditions. With grass driers, the 'standard' operating conditions are drying from an initial moisture content of 80% to a final moisture content of 10%. With grain drying the standard conditions at which capacity should be stated are for drying grain from a moisture content of 21% to 15%, at a hot air temperature of 66°C (150°F). Statements of output which do not define the initial and final moisture contents are usually either meaningless or misleading.

Grass drying

Increases in fuel costs during the 1970s resulted in substantially increased drying costs and seriously impaired the ability of grass drying to compete with other conservation methods where conserved green crops are for home consumption.

Moisture content

The moisture content of grass that is growing in the field depends on the type of herbage and its maturity, but in general it is around 75% to 85% (wet-base). In favourable drying weather, drying of the cut grass for a short time in the field can reduce moisture content to about 65% or even to below 60% moisture. The effect of this field drying or 'wilting' is important. If grass having an initial moisture content of 80% is dried down to 10%, 3½ tonnes of water have to be evaporated to produce 1 tonne of dried grass. At 70% initial moisture content, only 2 tonnes of water has to be removed to produce 1 tonne of dried grass, while at 60% the amount of water to be removed is less than 1½ tonnes. Thus a small difference in moisture percentage at high levels has a great effect on the amount of water to be evaporated. The figures serve to emphasise the value of 'wilting' where this is practicable.

It is difficult to justify the fuel and labour costs involved in drying unwilted grass in order to conserve it for stock feed for home consumption. For such purposes silage and barn-dried hay are strong competitors. With efficient

and well-run driers, however, there is a possibility of economic operation where a proportion of the product is sold for compounding or other purposes.

It should be noted that grass is not normally completely dried. If it is to be stored without grinding or cubing there is no point in drying it to below 10% moisture content. In fact, if really uniform drying were possible, 15% moisture content would be low enough for baled or chopped forage, since the crop will arrive at some such figure by reabsorbing moisture from the air after storage. The reason for not aiming at an average of above about 10% is the danger of having damper patches which would go mouldy. When grass is to be milled it pays to dry it down to about 6%, otherwise the mill requires an excessive amount of power, and blockages may result.

Drier capacities and efficiencies

The output of a drier in terms of dried grass produced per hour fluctuates widely according to initial moisture contents. The best measure of a grass drier's capacity is, therefore, its water evaporative capacity under working conditions; and the best measure of its efficiency is its consumption of fuel in J/kg (Btu/lb) of water evaporated. These figures are available for driers which have been officially tested. A typical good conveyor-type low-temperature grass drier with arrangements for recirculating the air that finishes the drying process should have a specific consumption within the range of 3.6–4.7 MJ/kg (1500 to 2000 Btu net/1 lb) of water evaporated. In terms of more common usage, a good efficiency for a grass drier is 90 to 100 lb of water evaporated per gallon of oil fuel (9–10 kg/l). Very small cheap plants with no recirculation may have much lower efficiencies than this, and some high-temperature driers may do a little better. All driers represent some sort of a compromise between the requirements of high efficiency and low capital cost.

Fuels

The fuel used in commercial grass driers is now usually heavy oil. Compared with solid fuels, oil has advantages in providing quick starting, allowing easy thermostatic control and needing little labour. A popular method of estimating the efficiency of drying is in terms of gallons

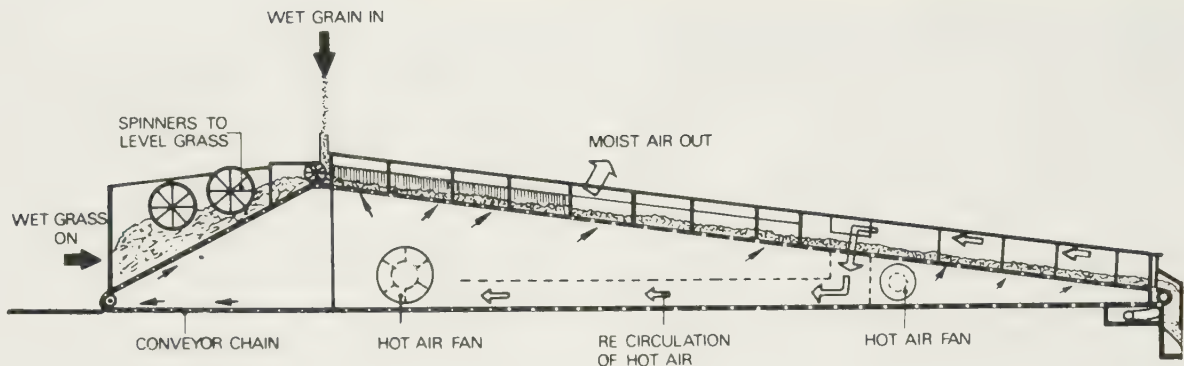


Fig. 18.1 Single-flow dual-purpose grass/grain conveyor drier.
(Alvan Blanch)

(litres) of oil burned per tonne of dried grass produced, but this, of course, varies considerably with wet grass moisture contents. With grass of 75% moisture dried to 10% an average figure of 400 l/tonne (90 gal/ton) is reasonable. In good weather, when full advantage can be obtained from field drying, figures below 60% of this are possible. On the other hand, in a wet season, when the moisture content of the incoming grass often exceeds 85%, oil consumption may be 30–40% above average.

Types of grass drier

Endless-belt conveyor driers

These comprise a drying chamber or chambers through which run one or more endless conveyors. One type of endless conveyor consists of a series of well-fitting perforated plates carried on chains and driven by sprocket at the end of the drier. Other types of conveyor are made of woven wire.

A simple and effective conveyor consists of a pair of chains and angle-iron slats which move over a stationary inclined steel bed, made up of overlapping louvres. This system is well suited to dual-purpose driers (e.g. Alvan Blanch).

The herbage must be fed on to the conveyor in a uniform layer, and modern machines are fitted with a self-feed device that will secure this with all but very long material. The self-feed mechanism usually consists essentially of a high-speed spinner which rotates above the grass beds and throws back any excess.

Practically all conveyor driers employ recirculation, the air that passes through the bed at the dry end being collected and led back to the furnace or to a mixing chamber which supplies part of the air to a second fan. Some driers employ two or three separate hot-air fans in addition to a cooling fan, with recirculation of air from one to the next until finally the air passes out to the atmosphere through the wet grass near the inlet end of the machine. Drying temperature may be 150–177°C (300–350°F) at the inlet end, about 120°C (250°F) at the second stage and about 105°C (200°F) at the third stage.

The ingoing material should be kept as uniform in moisture content as possible, and the bed should usually be maintained at the same thickness, control being achieved mainly by varying the speed of the conveyor. With full recirculation such driers can evaporate up to 10 kg of water per litre of fuel oil used (100 lb/gallon).

Some types of conveyor drier can be efficiently used as both grain and grass driers. Securing a satisfactory performance from such machines demands not only a properly designed drier, but also a well-planned installation which takes account of the needs in handling both grass and grain crops.

High temperature driers

These are usually of the rotary drum type or may employ a pneumatic tower and a rotary drum. All forms of high-temperature drier require the material to be chopped into short lengths. Advantages claimed for high-temperature driers are (a) that their thermal efficiency is

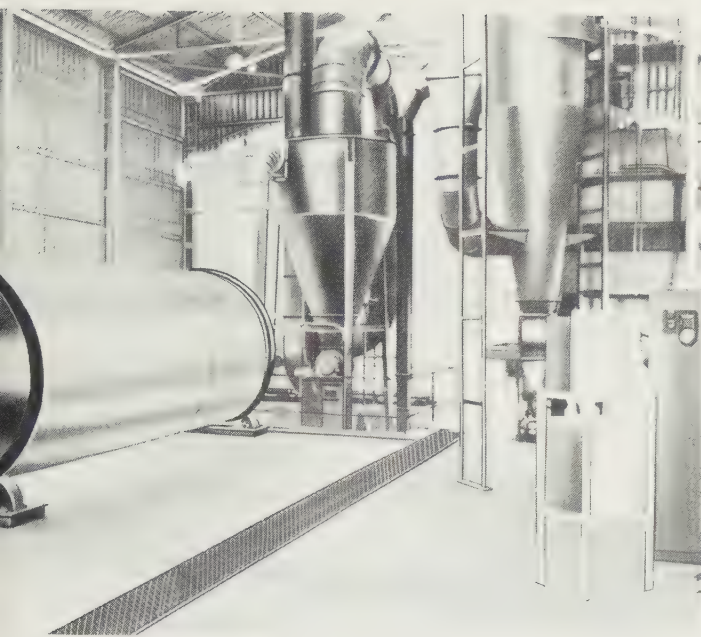


Fig. 18.2 High-temperature rotary drum grass drier.

higher than that of low-temperature machines, and (b) that they require less labour to operate. It is true that high-temperature driers can have high efficiencies in terms of water evaporative capacity, and they are seen at their best in drying very wet materials such as sugar beet tops. Unfortunately, it is not always possible to get the best out of such machines when they are required to handle such materials as wilted grass. The labour requirement of various types of drier is determined by the feed mechanism and not by the temperature at which the drier operates.

In a typical rotary drum drier the chopped grass is fed into the slowly rotating drum directly in the path of the hot gases, which are sucked through the drum by a fan at the discharge end. The temperature of the ingoing gases is usually of the order of 538°C (1000°F); light, leafy material is dried in a few seconds, and is then carried along in the air current and delivered to a large cyclone. The heavier, stemmy parts of the crop take longer to dry and to become airborne. During its passage through the drum the grass is constantly picked up by vanes on the inner circumference of the drum, taken by them to the top and dropped into the air stream. Staggered vertical baffles impede progress through the drum and increase

selectivity. The whole drum is maintained at a slight vacuum, and a high exhaust temperature of about $108\text{--}115^{\circ}\text{C}$ ($225\text{--}240^{\circ}\text{F}$) is usually maintained. In some driers the drum incorporates concentric cylinders which cause the crop to make a 'triple pass' through it. There is no fundamental difference between single-pass and triple-pass drums.

Single-stage high-temperature driers tend to be inefficient due to their allowing insufficient time for moisture to diffuse out of the stemmy parts. They often present the equally unattractive alternatives of over-drying and scorching the leaf, or under-drying the stem. In order to remedy this, two-stage and three-stage driers are employed. In the first stage, very high temperatures are used and the exhaust gases go to the atmosphere. In the second and third stages, lower temperatures are employed, and the exhaust gases are recirculated.

An example is the pneumatic tower and drum type. In the first stage, chopped grass is fed into an adjustable mechanical selector, which removes stones, etc., and also discards some of the grass if too much is accidentally fed in. The selector delivers the chopped grass into the main air stream, which passes up a tall tower and thence to a large cyclone, the exhaust passing directly to atmosphere. From the cyclone the grass passes on to two rotary drums, the first at about 260°C (500°F) and the second at a still lower temperature. Selection of dried material from wet continues at all stages of the process: the dry material passes rapidly to a position where it will not be burned.

In all types of drier in which really high temperatures are used, the gases and forage travel in the same direction (i.e. they are 'co-current'); by the time the material is dry enough to be inflammable, it should have travelled to a position where the temperature is low enough to preclude scorching or fire. So long as the herbage is moist, its temperature remains low, owing to evaporation; but it is rapidly spoiled if it remains at temperatures of 150°C (300°F) or over after it is dry. One of the earlier disadvantages of high-temperature driers was that control was difficult, and needed the more or less constant attention of an experienced man. Modern driers employ automatic controls which regulate the feed in relation to the temperature of the exhaust gases. These automatic controls are able to cope with minor variations in conditions, but need regular supervision and adjustment to look after major differences in conditions at different times of the day.

Collecting grass for drying

The machinery used for collecting green crops for drying does not differ fundamentally from that used for collecting crops for silage, described in Chapter 12. For supplying large-scale plants it may be necessary to provide some quite expensive equipment. High-output self-propelled tanker harvesters can hydraulically tip their hopper loads at high level into the road transport vehicles, which may conveniently be a very large 8-wheeled articulated type, enabling the trailer parts to be set down in the field while the traction units deliver their loads. On the other hand, much more conventional equipment of the type used for making wilted or high-dry-matter silage can be satisfactory for smaller farm-scale plants. As a general rule, a high-temperature drier will require a metered-chop forage harvester, while a longer chop may be used for conveyor driers.

Dried grass storage

Milling the dried grass requires fairly expensive equipment. If the moisture content were uniform at about 5%, a motor of 22–30 kW (25–40 hp) would be adequate to deal with the output of a $\frac{1}{2}$ ton/hour plant. In practice, however, damper patches are inevitable, and a mill of at least double this power is needed. A 1.5 mm ($\frac{1}{16}$ in) screen is usually quite fine enough. The meal may be stored in thick paper bags, and keeps its quality for long periods.

Where dried grass is produced for use by cattle or sheep, there appears to be some advantage in avoiding grinding, since ruminants tend to make better use of material in which some of the fibre is left in a fairly long form. Yet digestibility tends to be improved by cubing. An ideal package may be a wafer made out of chopped material, possibly with the addition of some binding agent which is a useful supplement to dried grass.

Many drying plants employ cubing machines, especially those where the dried grass is for sale. Grass meal, wafers or cubes should always be cool before being stored in bulk or sealed in bags.

Barn hay drying

In the barn hay drying process, haymaking machines are employed to get rid of moisture as rapidly as possible in

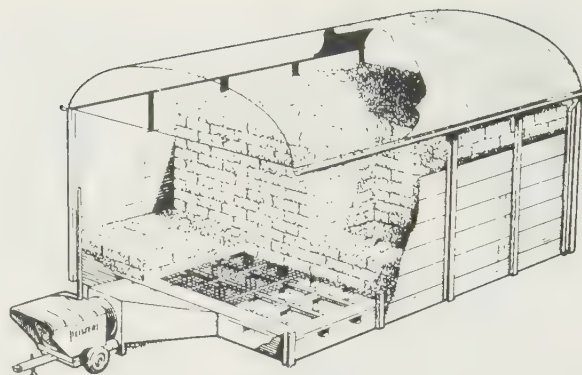


Fig. 18.3 Storage-type barn hay drier with mobile engine-driven fan. (*Econ-Lister*)

the field, and when the crop is partly dry, it is collected, and drying is completed by forced ventilation. The term ‘barn drying’ is applied to a wide range of methods, of which the following are typical.

Storage drying with perforated floor

For this method airtight side walls are needed, and an air speed through the crop of about $0.23 \text{ m}^3/\text{m}^2 \text{ per s}$ ($35\text{--}45 \text{ ft}^3/\text{min per ft}^2$) is recommended. A floor of welded reinforcing metal laid over timber joists is usually employed. The crop is normally loaded in baled form. A depth of 1.8–2.4 m (6–8 ft) is put in at a filling and no more added until this layer is reasonably dry. The crop must be uniformly dried in the field to a moisture content of no more than 45%, and preferably less. Axial-flow fans capable of operating against about 7.5 mbar (3 in w.g.) are generally employed. Total depths up to 6 m (20 ft) can be successfully dried. Cold or only slightly warmed air is used.

Batch driers

With batch driers the normal method of operation is to put in a batch of limited depth, e.g. 1.8–2.4 m (6–8 ft), and to remove this before the next batch is dried. The wall need not be more than about 2.4 m (8 ft) high, and provision of a heater is essential to ensure completion of the process within a limited time.

It is an advantage in this type of plant if an air speed of $0.3 \text{ m}^3/\text{m}^2 \text{ per s}$ ($50\text{--}60 \text{ ft}^3/\text{min per ft}^2$) can be provided

at the beginning of the operation. Later, when the crop has been dried to about 30% moisture content, air speed can be reduced to about $0.1\text{--}0.15\text{ m}^3/\text{m}^2\text{ per s}$ ($20\text{--}30\text{ ft}^3/\text{min per ft}^2$); it is an advantage then to use a temperature rise of about $11\text{--}14^\circ\text{C}$ ($20\text{--}25^\circ\text{F}$). This type of plant can successfully dry hay from about 55% moisture content, and can also dry grain in sacks if the floor is made strong enough to support the load.

Tunnel drying

Baled hay that is nearly fit for stacking can be conditioned by building the bales over a portable drying floor or into a tunnel and blowing through about $0.47\text{--}0.94\text{ m}^3/\text{s}$ ($1000\text{--}2000\text{ ft}^3/\text{min}$) of cold or slightly warmed air per ton of crop. The fan for this purpose may be a mobile unit, powered either by a tractor or by an engine built on a two-wheeled chassis. Where a stationary unit is employed beneath a Dutch barn, it may be arranged to blow into a large masonry duct from which a number of separate 'tunnels' of baled hay may be built out at right angles. A simple door controls the air-flow to individual tunnels.

Successful results have been obtained with unheated air, but there is more certainty of success where heat can be applied when atmospheric conditions make this desirable.

'Dutch' horizontal air-flow system

The main feature of the 'Dutch' system is the use of a central drying flue, which is formed in the hay by means of a rectangular 'bung unit' as the hay is stacked in the barn. Air passes horizontally through the crop, and where the stack is oblong in shape, it is necessary to form branch ducts running towards the more distant parts in order to equalise distances from the duct to the outside. There must be free escape of air from the outside, but it is advisable to build a few supports to keep the outside bales steady. One of the main advantages of the system is that airtight walls and a plenum chamber are not required. Delivery of air to the central flue is usually from an underground duct, but can be from a fan contained in the bung unit.

The Dutch system is less positive in action than the vertical air-flow systems. It is therefore necessary to limit moisture content of the crop to about 35% and to make sure that bale densities are uniform at about 160--



Fig. 18.4 A cheap building being used for a 'Dutch' hay-drying system. The fans are suspended from a rail so that they can be raised as filling proceeds, and to provide for movement from one bay to another. (*Electricity Council*)

180 kg/m^3 ($10\text{--}12\text{ lb/ft}^3$). Air-flow recommended is about $0.18\text{ m}^3/\text{m}^2\text{ per s}$ ($35\text{ ft}^3/\text{min per ft}^2$), at 6.2 mbar (2.5 in w.g.). Height can be up to about 6 m (20 ft). Maximum stack size is about 9 m (30 ft) square.

Centre-duct system

This is a system, similar to the tunnel and Dutch systems, in which the bales are stacked round a duct with open sides and top, running down the centre of the barn. Upper limit of moisture content is 40%, and air-flow required is $0.2\text{ m}^3/\text{m}^2\text{ per s}$ ($40\text{ ft}^3/\text{min per ft}^2$) at 7.5 mbar (3 in w.g.). Maximum dimensions are 6 m high by 9 m wide ($20 \times 30\text{ ft}$).

Drying big bales

Drying hay in big bales in Britain requires careful attention to many details, and can be extremely difficult in adverse conditions. Almost all successful installations are based on medium-density rectangular bales, $1.5 \times 1.5 \times 2.4\text{ m}$, uniformly field dried to no more than 35% mc, and preferably to 30% or less; and carefully baled at uniform

Farm Machinery

density to give a 'dry' weight of about 500 kg. Such bales typically weigh 600–700 kg when collected, and should be made as 'square' as possible.

The preferred system for practical large-scale drying where a suitable large building is available is a tunnel supported by a well designed framework. Every effort must be made to avoid air leaks between bales. Total drying time for bales of 30 to 35% mc, is likely to be 10–14 days. It is impossible to dry big bales efficiently if they are too wet and dense. In an ideal arrangement, the dried bales are stacked for storage about 5 high by RTFLT in a building opposite the drying tunnels.

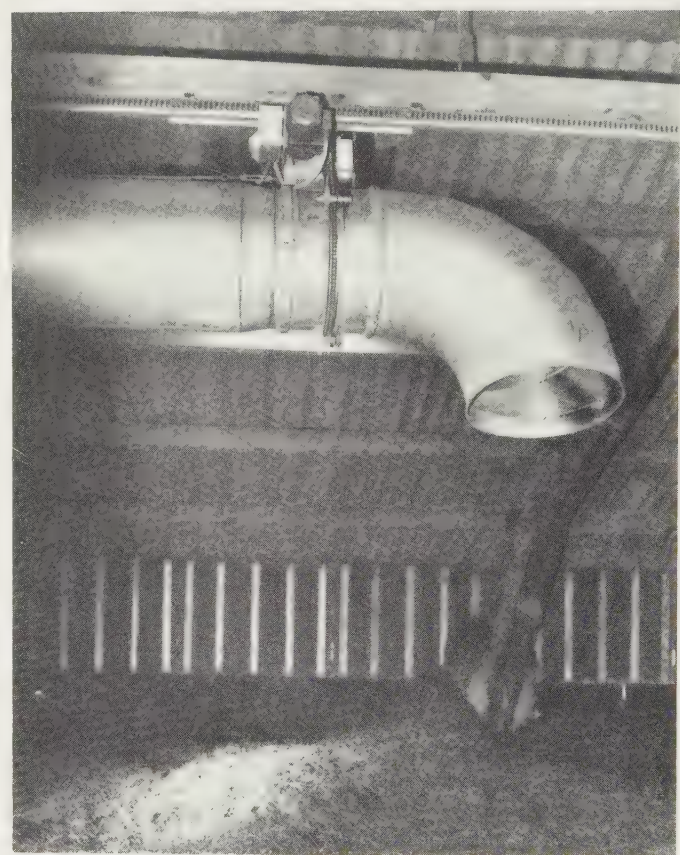


(a)

Barn drying loose hay

Methods of handling loose hay from field to farm are briefly reviewed in Chapter 13. Success in drying and feeding such material in British conditions depends on having a well-engineered installation which makes it easy to distribute the crop automatically in even shallow layers over a fairly large drying area. In a method of Continental origin, material collected by loader wagon is distributed by dump box and forage blower to a large-diameter oscillating outlet which is swung from side to side by one small motor and moved along a rail running the length of the drying area by another. Movement along the rail is made possible by a series of 2 m long telescopic sections in the straight horizontal part of the delivery pipe (e.g. Neuero; Schwarting). When properly set, the drying system can result in a system of low resistance to air flow, capable of economic drying of well-wilted crops using unheated air. Unloading and feeding can be by removing sheeting from one end of the barn and using a high-lift grab on a tractor or a telescopic boom handling vehicle.

The equipment needed for automatic loading is not cheap, but the building can be a multi-purpose kind employing a ventilating floor which is removed in sections. A slatted type in sections 1.5×1.2 m raised 0.3 m above an earth floor can be satisfactory. Modern loader wagons give a suitable chop length for drying and for feeding by wagon or from stationary racks.



(b)

Economic aspects

On most farms production of barn-dried hay has to be compared either with silage-making or with hay made in the field. It is usually necessary to compare the extra

Fig. 18.5 Chopped hay drying.

(a) Filling drier, using forage wagon, dump box and tractor-driven forage blower. (Neuero)

(b) Distributing hay in drier by oscillating-neck telescopic pipe with delivery point automatically driven to and fro by rack and pinion along the centre of the drying barn. (Electricity Council)

costs of barn drying over field haymaking, with the improvement in quality, added to any saving of crop that would otherwise have been lost.

Extra costs include:

- (1) *Fixed costs*, based on depreciation, etc. Fixed costs can easily be excessive if very expensive structures are built.
- (2) *Running costs* depend chiefly on the initial moisture content of the hay as it is loaded into the drier and, of course, on the consumption and price per unit of oil and/or electricity.

Any kind of barn drying demands careful management to ensure success. It is essential to carry out swath treatment operations soon after cutting, and to continue treatments as necessary, so as to ensure that moisture is removed rapidly and uniformly. With conventional bales, care must be taken with the baling operation to ensure that the bales are not too tight and not too long. Full-length bales may be suitable if the crop is nearly dry, but a length of about 0.76 m (30 in) is sufficient if the crop contains more than about 45% moisture when baled.

The extra benefits of barn drying are not easily measured, but careful experiments have shown that they are appreciable. One benefit is an increased yield

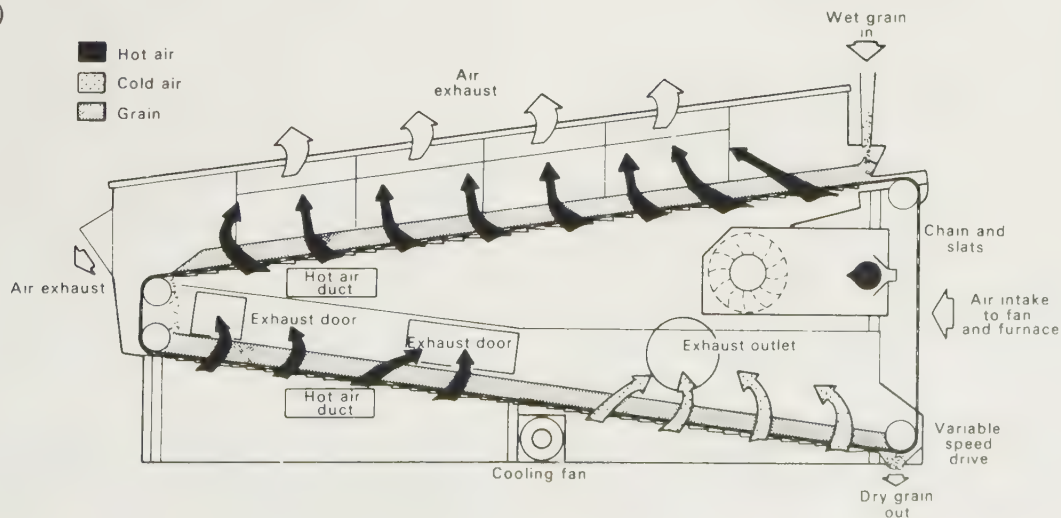
compared with field-made hay. A 10% increase is common. Feeding experiments have also shown differences in quality which are particularly marked in seasons when field-made hay is spoiled by rain. Barn drying provides a certainty of crop conservation comparable with that of silage-making.

Grain drying

Grain, as harvested by the combine, often contains 20% or more moisture, and it is necessary to reduce this before safe storage in ordinary bins is possible. Grain containing 16% moisture may be stored if it is turned occasionally, or if it is in sacks. Grain with 18% moisture will generally keep for a short period if stored in sacks which are well spread out and have their mouths open. The farmer who risks using combines without the help of a drier is at a disadvantage, for he must always wait for the grain to dry before he can start work. The use of a drier makes it possible to work the combine more hours per day, and this is important in a wet harvest.

Driers designed for handling grain include (1) continuous-flow driers, (2) batch driers, (3) ventilated bin driers and (4) 'on-floor' driers. These are briefly dealt with in the following pages.

Fig. 18.6 Double-flow louvred-bed conveyor drier for grain.
(Alvan Blanch)



Continuous driers

Continuous driers extract the moisture fairly rapidly, the usual time taken for individual grains to pass right through the machine being about an hour. In order to economise in size of plant but to maintain a good drying speed, fairly high temperatures are usually employed, and the grain is treated in thin layers. Heat is provided by an oil burner, or sometimes by electricity, or steam heat exchanger. In tower driers, the grain is fed into a hopper at the top of the drier and moves continuously downwards through the machine, usually between perforated metal plates so arranged as to form walls of grain, about 150–300 mm (6–12 in) thick. The hot gases are blown or sucked through the grain, which gradually becomes drier as it falls to the bottom of the machine. The rate of flow of grain through the drier is variable, and is controlled by the speed of a conveyor, which removes the dried grain from the bottom. Samples of grain that are very wet must, of course, be passed slowly through the machine.

Grain drier developments

The term *cross-flow* is applied to types where the grain is confined between sheets of perforated metal, usually arranged on the sides of a rectangular tower so that the drying air passes horizontally through the grain walls, at right angles to the grain flow. Aims in improved designs include avoiding over-heating or over-drying individual grains, by such methods as providing inclines to turn and mix the grain, or reversing the direction of air flow at successive levels.

The term *mixed-flow* (Fig. 18.7) is applied mainly to driers with alternate layers of open-bottom inverted U or V ducts for air entry and exhaust. Part of the air from each entry duct moves upwards against the direction of grain flow, and the rest downwards with the grain, to reach the exhaust ducts. Ducts may be tapered from end to end to keep air speed along them substantially constant. Usual arrangement in advanced continuous-flow types is a buffer zone at the top, drying zone in the middle and cooling at the bottom. A proportion of the cooling air may be re-used for drying.

A *counter-flow* system (Fig. 18.8) is employed in a few medium-temperature driers of North American origin where the dried grain is removed by a tapered sweep

auger which moves round the bottom of a perforated-floor cylindrical bin. In practice each sweep of the auger removes a grain layer about 150 mm (6 in) deep. Average exit temperature of this grain is typically about 25°C lower than the entry temperature of the drying air. Positive arrangements for cooling in a separate bin are usually essential, both to ensure safe storage and to achieve the good drying performance of which the counter-flow system is capable.

Drying maize and rice from very high moisture contents (e.g. 35%) is a normal requirement in some countries but not in Britain. Such needs can justify systems that are high in capital cost if they achieve some economy in inevitably high running costs and result in products of good quality.

Dryeration is a term applied to a process first developed in the USA to prevent 'stress cracking' of maize and rice, and subsequently adopted more widely for a type of drying process adapted to suit most grains dried from high moisture levels. The basis is that the first drying is stopped at a grain moisture content 2–3% above the required storage moisture level, and instead of being immediately cooled by blowing with atmospheric air, the grain is transferred to a bin where it is left to sweat for several hours, thereby giving internal grain moisture time to move to the surface, where it is later removed by low volumes of unheated air. Several tempering and final cooling bins may be needed, and much time (e.g. up to 30 hours) involved. For drying cereals from more usual much lower moisture levels, however, a much shorter tempering period can be used and adapted to the throughput of a continuous-flow drying system (e.g. Law-Denis). Other modern driers (e.g. DRY-MOR) employ two separate drying sections and a system of switching the drying air flow from one side to the other every 15 seconds. This is claimed to improve drying efficiency by giving the drying air time to come nearer to its saturation capacity before it is exhausted.

'Cascade' driers are in some respects intermediate between tower driers and horizontal conveyor machines. The grain is fed from a hopper at the top of the machine into an inclined trough which has a louvred floor through which the drying air is blown. As dry grain is removed from the bottom of the slope, more damp grain comes down the slope to take its place. Mechanical means of moving grain through continuous driers include use of horizontal chain-and-slat conveyors.

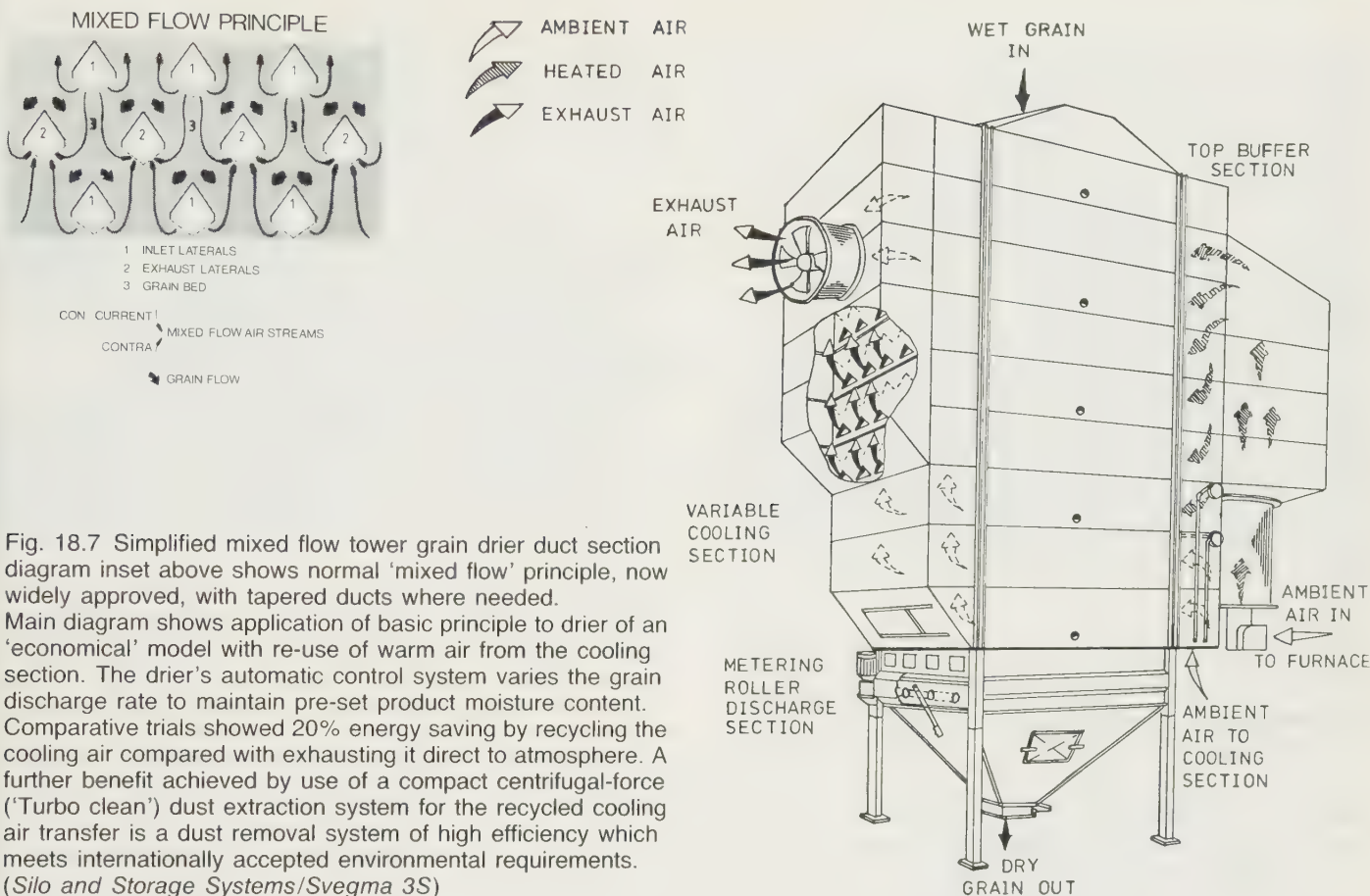


Fig. 18.7 Simplified mixed flow tower grain drier duct section diagram inset above shows normal 'mixed flow' principle, now widely approved, with tapered ducts where needed. Main diagram shows application of basic principle to drier of an 'economical' model with re-use of warm air from the cooling section. The drier's automatic control system varies the grain discharge rate to maintain pre-set product moisture content. Comparative trials showed 20% energy saving by recycling the cooling air compared with exhausting it direct to atmosphere. A further benefit achieved by use of a compact centrifugal-force ('Turbo clean') dust extraction system for the recycled cooling air transfer is a dust removal system of high efficiency which meets internationally accepted environmental requirements. (*Silo and Storage Systems/Svegma 3S*)

In one endless conveyor type the louvred bed is slightly inclined but the movement of the grain down the slope is regulated by controlling the speed of a slow-moving chain-and-slat conveyor. In a 'double-flow' type, the grain from an upper incline falls on to a second which runs back to a point below the grain inlet. This facilitates handling and economises in conveying equipment, while making it practicable for the drier itself to stand outside the building used for handling and storage (Fig. 18.6).

With any modern drier installation, arrangements should be made to deliver the moisture-laden air to the outside.

Horizontal or inclined driers require more floor space than tower driers of equivalent capacity, but can be housed in a lower building, such as a lean-to. Use of a lean-to

outside the main building is a simple way of avoiding a dust problem. The layout of conveying equipment with single conveyor types is less compact than with a tower drier but with modern equipment there is no serious difficulty in achieving a satisfactory layout.

Operation of continuous driers

Experimentation and experience over a long period have shown that an increase of drying temperature will considerably increase output, but that there is a danger of damage to germination or baking quality if grain intended for seed, malting or flour milling is dried at too high a temperature. Driers differ in their safe drying temperatures, depending on such factors as reliability of thermo-

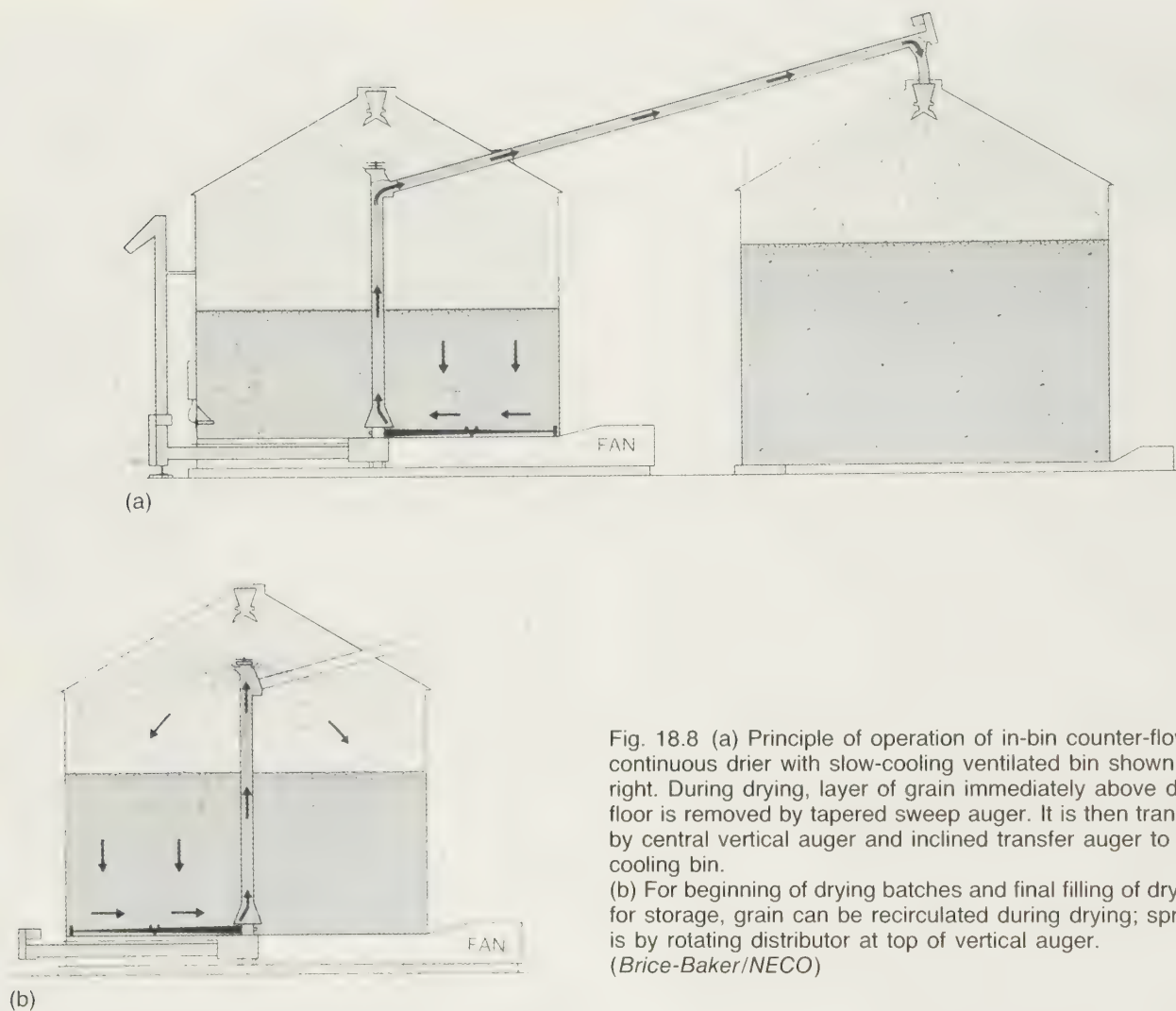


Fig. 18.8 (a) Principle of operation of in-bin counter-flow continuous drier with slow-cooling ventilated bin shown on right. During drying, layer of grain immediately above drying floor is removed by tapered sweep auger. It is then transferred by central vertical auger and inclined transfer auger to the cooling bin.

(b) For beginning of drying batches and final filling of drying bin for storage, grain can be recirculated during drying; spreading is by rotating distributor at top of vertical auger. (Brice-Baker/NECO)

meters, uniformity of temperature in different parts of the air stream, reliability of grain movement and turning devices, etc. In the absence of proof that high temperatures can be safely used, it is advisable to stick to the following figures:

Feed corn for home consumption	105°C	(220°F)
Wheat for milling	66°C	(150°F)
Barley for malting, or seed corn		
up to 24% m.c.	49°C	(120°F)
over 24 m.c.	44°C	(110°F)
Mustard, linseed, etc.	46°C	(115°F)

These temperatures are known to be conservative. Research in Britain and elsewhere, for example, shows that in a perfect drier, fairly dry wheat can be dried at up to 80°C (175°F) before damage to the gluten occurs; but for the reasons given above, higher temperatures than those listed should only be used if adequate independent tests of the particular drier have shown them to be safe.

There are two main ways of ensuring that a large bulk of grain dried in a continuous drier will maintain its condition in store. One method is to make sure that it is all dried to 14% moisture content and is thoroughly cool (to not over 18°C (65°F)) before putting it into store.



Fig. 18.9 Mobile continuous-flow gas-fired drier operated by tractor pto. Grain is levelled at top by horizontal auger, and flows by gravity over the inverted-V-shaped air ducts. (*Vertec*)

This is, of course, not practicable when the ambient temperature is high, and even if the grain is uniformly dried, putting some of it into store at about 32°C (90°F) on a hot day can lead to convection currents in the mass which may redistribute moisture and ultimately cause heating. For this reason, and because grain which can be positively cooled can be stored at a higher moisture content, there is much to be said for equipping bulk stores in such a way that atmospheric or chilled air can be blown through the grain mass. This subject is dealt with later. Where even simple mass cooling arrangements are provided, grain can leave the drier at higher moisture contents and temperatures, and this can lead to higher throughput by the drier, as well as to the important benefits of being able to store at higher moisture content.

A continuous drier needs adequate storage capacity for damp grain, so that it can accommodate the production from the combines during the day, and continue with drying during the night if necessary. It is sometimes convenient to fill the pre-drying bin from the overflow of the elevator that feeds the drier. It used to be a considerable advantage to have a divided wet grain pit, to facilitate changing over from one crop to another; a better solution is



Fig. 18.10 Mobile batch grain drier with pto and V-belt drive to axial flow fan; gas modulating burner; high-speed filling and emptying, and continuous recirculation and agitation of grain during drying. Grain elevated from mobile hopper by horizontal lower and central vertical augers cascades over cone-shaped top of plenum chamber. Drying and cooling air passes from plenum through 46 cm (18 in) cylindrical grain layer to atmosphere. Use out-doors is recommended. Typical drying cycle (including filling and emptying) for 5% m.c. removal is about 2 hours. Automatic controls for end of drying and safety are standard. Batch size of model shown is 500 bushels. (*Opico Model 580S*)

a fairly small single pit, a high-capacity elevator and ample pre-drying storage.

Where tipping trailers are used it is usually convenient to build a parapet about 300 mm (12 in) high to increase the pit capacity and keep out water and rubbish; with non-tipping vehicles a run-over pit covered by a grille is preferable. The sides of the pit should be made to slope at an angle of about 45°.

When the grain is very wet, the discharge mechanism is adjusted to give a long drying period, and the moisture content of the dry grain must be checked to see that drying is adequate. If it is not, it may be necessary to dry the grain partially in the first operation and to redry it as soon as possible. In good harvesting conditions, on the other hand, the grain may be adequately dried if passed through the machine as fast as possible, or may not need

drying at all. With oil-fired driers the burner is thermostatically controlled at the desired drying temperature, and temperature is not normally varied in order to adjust out-going grain moisture content. With all types of continuous drier, the grain that is in the drier at the beginning of work will not be properly dried. It should be returned to the receiving pit or drier and mixed with incoming grain.

Automatic grain moisture content controllers

Cheap and effective devices for automatic control of grain

moisture content in continuous driers can greatly reduce the amount of supervision needed during drying, and can produce results better than those achieved by manual control. The method of control is relatively simple. The moisture content of the grain just before it leaves the drier is metered at short and regular intervals, by means of an instrument usually of electrical resistance and/or capacitance type. If the moisture content indicated is appreciably higher or lower than the pre-selected figure, an electrical relay sets in motion a device which starts or stops the mechanism that removes grain from the drier (see Fig. 18.11).

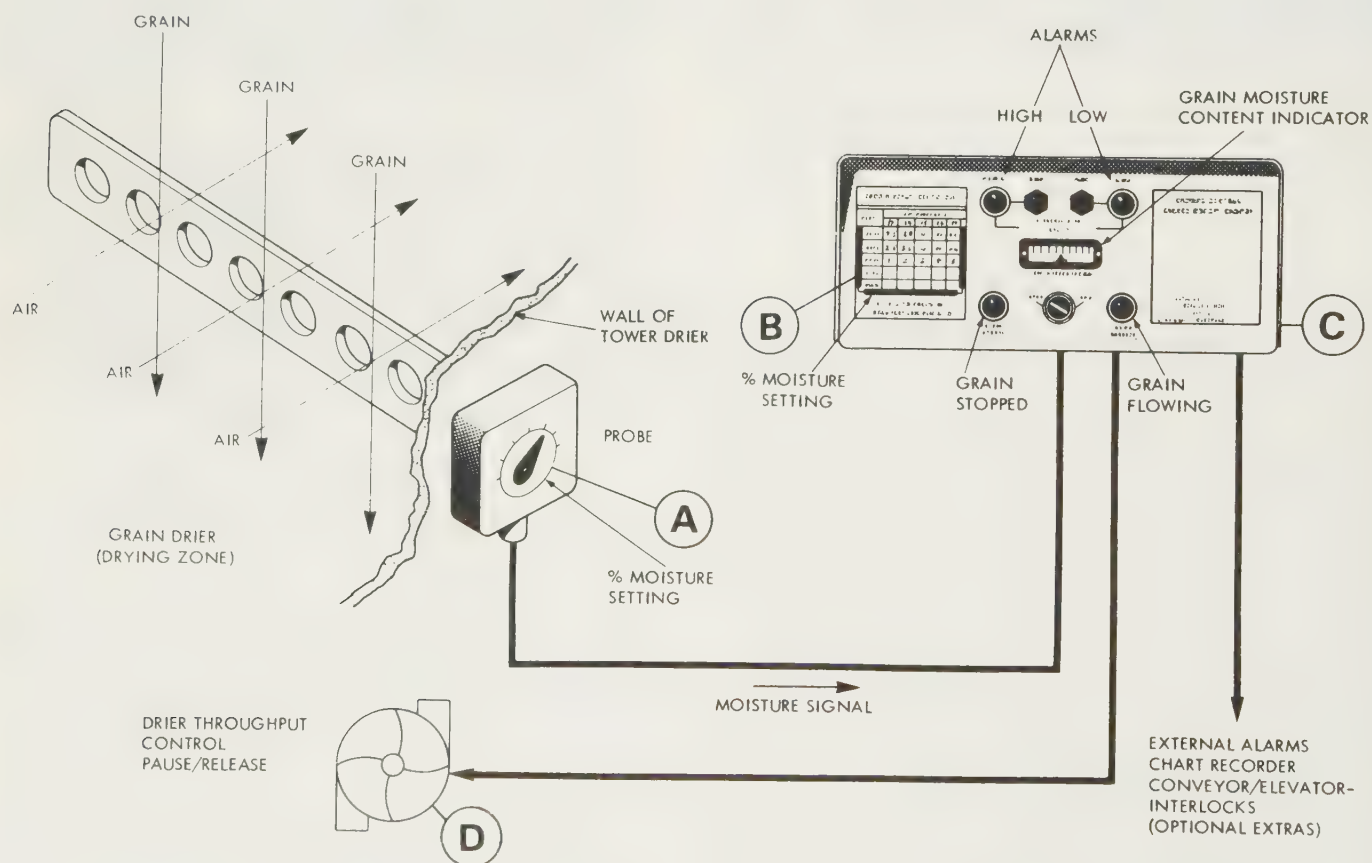


Fig. 18.11 Automatic grain moisture content controller. A measuring cell is formed between Probe A and the metal walls of the drier. Grain moisture content signal stops or re-starts mechanism that removes grain from the drier. (*Hunting Electrocontrols*)

Batch type grain driers

Some continuous cross-flow and mixed-flow driers are available also as batch driers: some are mobile, and suitable for on-farm contract work. Several have a round-bin conformation with a central vertical auger used for filling, emptying, and sometimes for grain circulation during drying. In a mobile type (e.g. Opico GT) the vertical cylindrical drying chamber enclosed by perforated metal has 1.6 mm ($\frac{1}{16}$ in) perforations and a grain layer 0.46 m (18 in) thick. Drying and cooling are usually effected in turn using a single fan; and a single auger system serves for loading, recirculation and unloading. To obtain a good throughput it is necessary to incorporate an effective semi-automatic handling system. More complex designs with separate drying and cooling fans provide for filling and emptying to proceed at the same time as drying and cooling. Automatic control provides a modulated grain discharge from the bottom of the cooling area by metering fingers delivering to a separate short unloading auger on a continuous flow basis.

Automatic batch driers

In a typical batch drier with automatic controls, when the hopper is full, a pressure switch stops the filling mechanism and starts the fan and gas or oil burner. The length of the drying time can then be controlled either by a pre-set time clock, or by an automatic moisture controller which senses the relative temperatures of incoming and exhaust air. At the end of drying, the burner is switched off while the fan continues to run and so cools the batch, length of cooling time being also pre-set on a time clock. After operation of the emptying augers, the bottom pressure switch indicates when the drier is empty, and the whole cycle recommences.

A modern grain recirculating mobile drier as illustrated in Fig. 18.12 can operate easily at any farm with a reasonably located three-phase electricity supply and a little preliminary planning on use of three-phase augers, one for loading and a second for unloading.

For maximum throughput, which can be up to 90 tonnes at 5% moisture reduction in 24 hours, it is worthwhile to plan for unloading at a fairly early stage of cooling, and transfer to a separate cooling silo where a small cooling fan can be used at times when the atmospheric conditions not only provide rapid cooling, but in



Fig. 18.12 Fully automatic recirculating batch grain drier with DCM control system. Throughput is up to 90 tonnes at 5% moisture reduction per 24 hours. (*Opico Model 3800A*)

the early stages can continue moisture removal in the cooling silo, in addition to the main objective of heat removal. With good auxiliary facilities the control programme runs as follows:

- (1) Operator activates loading auger.
- (2) Level sensor switches off loading auger when drier is full.
- (3) Burner is automatically lighted and cycles between temperature levels needed for specific drying programme.
- (4) When drying nears completion, burner is switched off, and setting for cooling provides appropriate short cooling period in drier or switches to direct unloading to cooling silo as decided by operator.

- (5) When drier is empty, grain level switch can activate beginning of the next batch.

Larger grain quantities can be handled by top-of-range models.

Ventilated bins

A ventilated bulk storage system consists essentially of a fan and heater unit to provide a supply of slightly warmed air, ducting to convey the air to the grain, and some method of distributing the air so that it passes through the grain in the store. Where large quantities of grain are to be dealt with it becomes desirable to add such auxiliaries as a damp grain receiving hopper, grain cleaning equipment and conveying equipment to enable easy movement of the grain into and out of the store, or from one part of the system to another. The chief fundamental principle of operation of deep bulk driers may be readily understood by reference to Fig. 18.13, which shows the effect of continuously blowing grain with air of varying

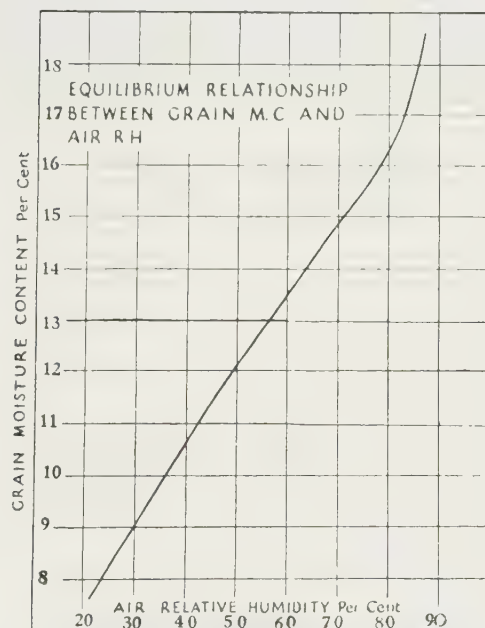


Fig. 18.13 Equilibrium relationship between grain moisture content and air relative humidity. (drawing Silsoe Research Institute)

degrees of relative humidity. It may be seen that for the production of grain of a moisture content of 14% – the figure necessary for prolonged storage in bulk without further ventilation – the relative humidity of the drying air needs to be about 60–65%. The mean relative humidity of the atmosphere of the drier parts of Britain over 24 hours during harvest time varies from 75 to 85%, and continuous ventilation with such atmospheric air will in practice produce grain having a moisture content of around 17–18%. It is necessary to warm or dry the air to produce grain of lower moisture content, and the amount of change needed varies with weather conditions. In cold, wet weather, the average temperature increase needed over the 24 hours to reduce grain to 14% m.c. is about 3–5.5°C (6–10°F), whereas 0–3°C (0–6°F) temperature rise is adequate in hot, dry weather. If very little drying is needed and the fan has only to be operated in the daytime in good weather, very little heating may be satisfactory; but farmers who plan to install ventilated bins in wetter areas would be well advised to provide for full utilisation where this is practicable. Heat is usually provided by electric heater elements, and the approximate requirement for 5.5°C (10°F) temperature rise is 3 kW per 0.47 m³/s (1000 ft³/min) of air. It should be possible to switch heat on in stages, so that adjustment may be made for the amount of air being blown and for long-term weather changes. In large stores it is not necessary to design for 5.5°C (10°F) temperature rise for full fan capacity, since it is very seldom that the whole store has to be blown in adverse conditions.

The rate of air-flow through the bins needed for effective drying is preferably not less than 0.1 m/s (20 ft/min). To remove an average of $\frac{1}{2}\%$ moisture per day from a bin containing 3 m (10 ft) of wheat, an air-flow a little above this is required, and this rate should be obtainable when blowing about half of the bins.

The bin floor is an important part of the installation. It must be completely grain-tight, and should create only a small resistance to air-flow when covered with grain. It must also be smooth, so that all grain can be easily swept off. Suitable materials include wedge wire, perforated metal and expanded metal.

Drying proceeds from the bottom of the bin upwards, and after it has been in progress for a day or two there are three distinct layers in the bin: dry grain at the bottom, a drying layer in the middle and a layer where no drying has taken place at the top. The rate at which

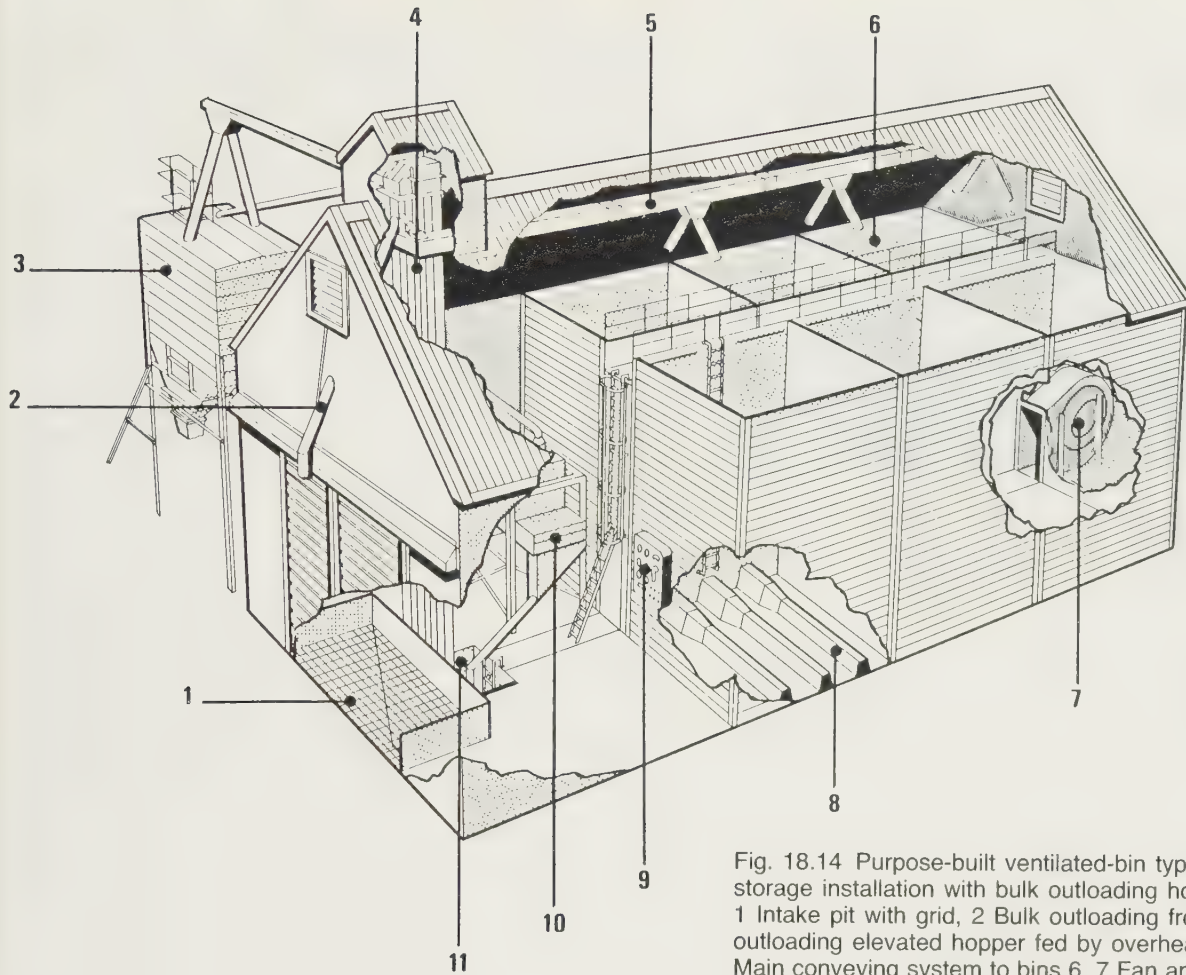


Fig. 18.14 Purpose-built ventilated-bin type grain drying and storage installation with bulk outloading hopper. (Rowlands)
 1 Intake pit with grid, 2 Bulk outloading from elevator, 3 Bulk outloading elevated hopper fed by overhead conveyor, 4, 5 Main conveying system to bins, 6, 7 Fan and heaters delivering air to main duct, 8 Lateral ducts combine drying, conditioning and air-assisted emptying or turning via bottom conveyor, 9 Control panel, 10 Pre-cleaner/grader, 11 Elevator pit.

the dry zone moves upwards depends not so much on the temperature of the ventilating air as on the original moisture content of the grain. Thus, if only 1–2% moisture content has to be removed, drying should be complete in a 3 m (10 ft) deep bin in 3 or 4 days; but if the grain originally contains over 20% moisture content it may be 10 days or more before the grain at the top is reasonably dry. Further heating of the air in such cases merely overdries the bottom layers, and has little effect on the time taken to dry the top.

One remedy for dealing with very damp grain is, therefore, to dry it in shallow layers. Grain of over 20%

moisture should first be dealt with in layers not exceeding 1.5 m (5 ft) deep. It can be moved and bulked to full depth after a few days' drying. It should be emphasised that ventilated bin plants are at their best in areas where most of the corn can be harvested at moisture contents not exceeding 20%.

A convenient and effective way of emptying either floor-ventilated or radially ventilated bins is to fit a directionally louvred floor which can be used in conjunction with the main fan to complete emptying by blowing the grain to the outlet. For successful emptying, it is necessary to be able to supply an air-flow of about 100 ft³/min per



Fig. 18.15 Group of cylindrical outdoor ventilated bins with central filling and emptying by mobile augers.

ft² of floor area at 4–5 in w.g. (0.5 m³/m² per s at 10–12.5 mbar) at the start, and about 130 ft³/min per ft² at 1½ in w.g. (0.65 m³/m² per s at 3.7 mbar) in the final stages.

Air conditioning by direct de-humidification

Dehumidifiers to assist bulk grain drying when relative humidity of atmospheric air is too high and temperature too low consist basically of a heat pump having the same essential components as a direct expansion type refrigeration unit as used in a cold store. The ambient air in being drawn over the evaporator coils of the refrigeration system is cooled below its dewpoint temperature: water condenses, and is allowed to drain away. The dried air is then reheated as it is drawn through the condenser element of the heat pump, raising its temperature by about 2–3°C above ambient. It is therefore much drier, with its R.H. reduced to around 30 to 50%. This air is mixed in the proportion approximately 1:2 with ambient air for use in the drier, so that after delivery through the main drying fan the R.H. is 60–70%, i.e. suitable for drying grain in bulk to a moisture content of about 15% mc.

The whole system is inherently energy-efficient, and many reputable manufacturers offer good equipment, suitable for use with any of the usual forms of bulk grain

stores popular in the more favoured areas of Britain. Main attractions to users include reliability and ease of management of equipment well chosen for the situation. In normal circumstances the units can be switched on and left to automatic control until near the end of drying. In periods of very high ambient relative humidity in late autumn their energy efficiency is well maintained, and operating cost comparisons with direct heating by electricity, gas or oil are favourable to the heat pump system.

When the attractions of drying grain in bulk in climatically favoured areas are considered it is surprising that it took about 40 years to develop systems that can compete with high-temperature driers in areas of intermediate climate where grain moisture contents at harvest are often over 20% mc and atmospheric air from early September onwards typically over 65% R.H. even in daylight hours.

Improvements in relative humidity sensors and applications of reliable control to propane burners showed the way, and soon the manufacturer of the HARVEST CHC 23 Automatic Constant Humidity Controller had sufficient confidence in the product to commission a private independent assessment of the progress by ADAS Mechanisation Department. In 1988, the easily mobile solid state electronic humidity sensing system (with propane air heater) that immediately adjusts the burner had more than satisfied purchasers interviewed by the RASE Machinery Awards judges: the entrant received the Society's Gold Medal award: and the manufacturer was able to supply to potential users a copy of RASE Report of User Experience No. 88004G. Such equipment is accurate enough and cheap enough to be worth consideration for floor driers and in-bin driers that are basically sound but often need to reduce the R.H. of the drying air accurately and at minimum capital outlay.

Grain chilling

Effective mobile grain chilling units have been available to farms with a normal electricity supply for a long time, and a note on some basic factors concerning natural cooling is included on p. 308. It was established in the 1950s that there is no future in long-term chilling in order to store grain at a high moisture content: but chilling can be very useful if grain comes into bulk store at a high temperature either from a drier or direct from the field in hot weather. In either case 24 hours of blowing with a suitable

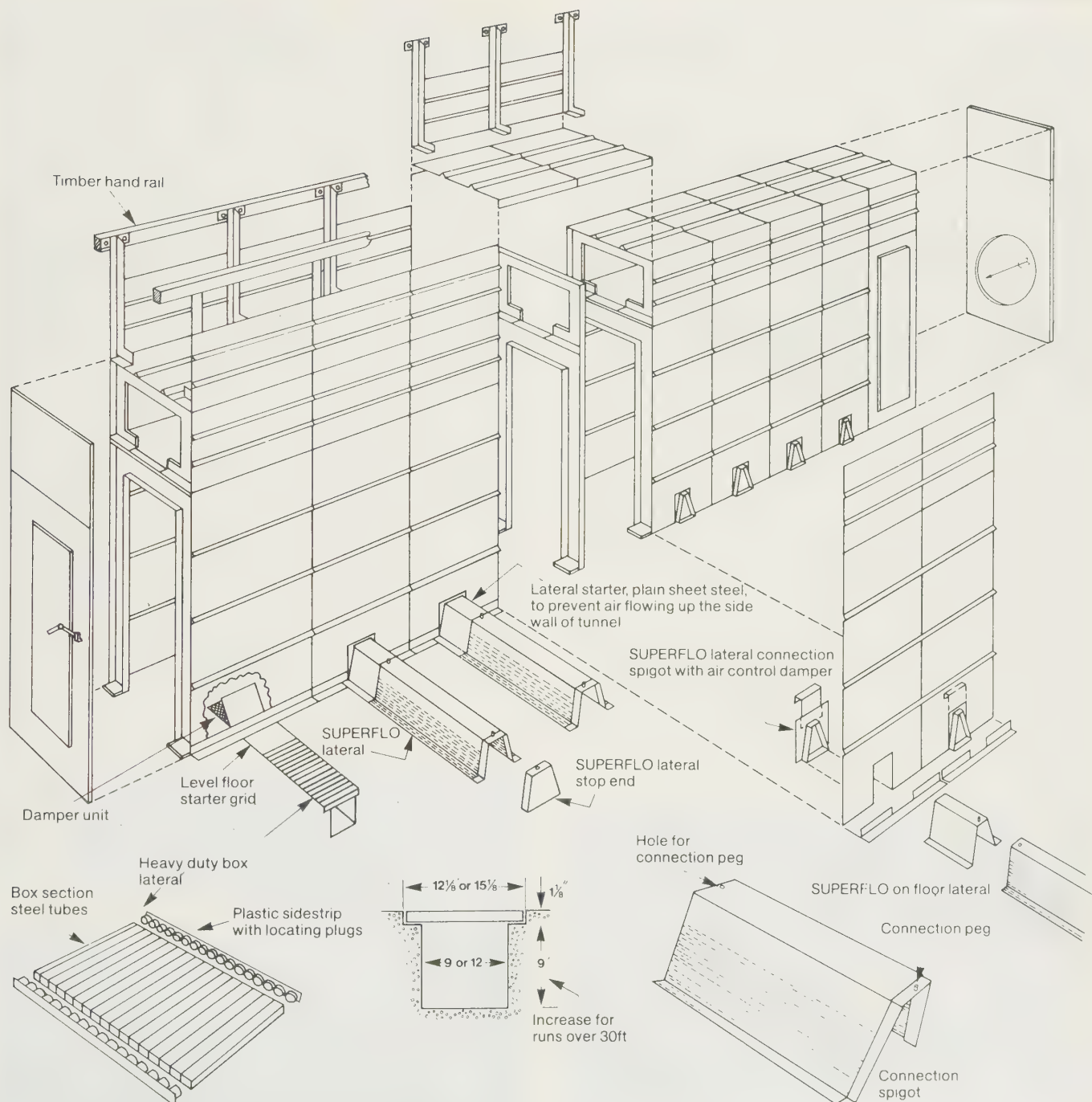


Fig. 18.16 On-floor drying. General arrangement of main duct, 'on-floor' laterals and 'level-floor' lateral grids. Spacing between the box-section 25 mm tubes for grain is 2.4 mm ($\frac{3}{32}$ in). 11 mm spacing is used for vegetables, e.g. onions. (Myson)

unit at a rate of only about 40 cfm/ton can effectively reduce temperature to a safe level and also remove about 0.5% mc if needed.

On-floor driers

'On-floor' drying and storage systems are widely employed on farms of all types and sizes in the main grain production areas of Britain. There is a wide choice of equipment for lateral air distribution, and while provision of an adequate and effectively controlled air flow through the grain must be considered essential, there are other factors of importance that provide scope for individual preferences. These concern capital cost, flexibility in future use of the building, and grain handling efficiency.

A basic consideration is the choice between above-ground and below-ground lateral air distribution. Above-ground ducts provide for maximum flexibility in building use and low capital cost; on the other hand, the best and more expensive below-ground distribution systems can provide highly efficient mechanical handling, enabling tractor operated vehicles and bulk lorries to run over the floor, and permitting effective use of a large grain bucket on a tractor front loader or RTFLT.

Lateral ducts of adequate dimensions for the necessary air-flow must be provided, and it is advisable to space them at 1.2 m (4 ft) centres or closer. All-metal ducts made of louvred or expanded metal are available in a variety of shapes and sizes. They can be strong and easy to handle. Length of laterals can be 12 m (40 ft) or more, provided that cross-sectional area is sufficient to limit air speed in the first part of the duct to about 10 m/s (2000 ft/min).

Air-flow to the laterals may be controlled by entering the main duct, which needs to be made a convenient shape and size to permit this.

It must be borne in mind that barn walls which were built many years ago for other purposes are likely to be completely unsuitable for supporting the side thrust of grain in bulk, even if the depth is only 1.8 m (6 ft) or so. The floor and walls must also be damp-proofed.

Provided that the walls are strong enough, a grain depth of 2.5–3 m (8–10 ft) is generally satisfactory. Because floor stores are normally filled and emptied only once a year, the fact that the portable lateral ducts have to be laid down and picked up again is not of itself a

serious disadvantage; for most farmers it is a considerable advantage that the building with its solid floor is cheap and simple to construct, and can easily be thoroughly cleaned out. Many farmers, however, object to the limitations which above-ground lateral ducts impose.

Methods of avoiding the use of above-ground portable lateral ducts include (a) construction of a floor in which the ducts are cast below-ground in the concrete, the tops of the ducts being formed by framed sections which are laid in rebates in the concrete. The louvred galvanised grids 920×305 mm (3 ft $\times$ 1 ft) may be rebated 38 mm ($1\frac{1}{2}$ in) into the tops of 230 mm wide (9 in) ducts; (b) U-shaped galvanised steel troughs may be inserted in the concrete as the floor is laid down, and use made of linked duct covers specially designed for strength, grain-tightness, free air flow and suitability for use with loader buckets.

Purpose-built removable ventilated flat-top floors are available in either metal and timber (Fig. 18.17) or metal and pre-cast concrete blocks. A sound system for the latter, where a multi-crop surface for either grain or root vegetables is required, is by use of removable metal inserts of narrow bridge shape dropping into precisely cast slots which ensure location of the metal surface just below concrete surface level. In an example ('Lincoln' ventilated floor), 6.75% free air space is available for vegetable crops and 3.75% for the grain inserts.



Fig. 18.17 Sectional multi-purpose drying floor of hardwood with inserts of perforated metal. (Challow)

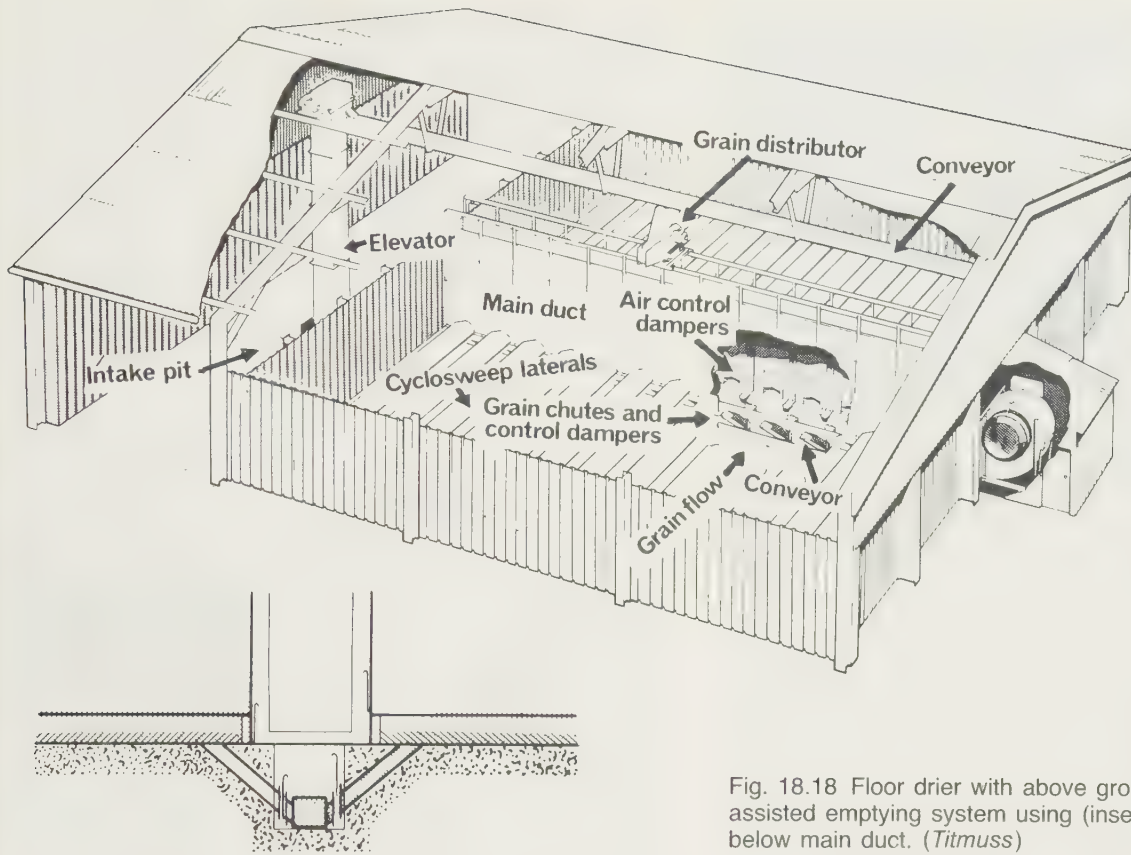


Fig. 18.18 Floor drier with above ground ducts and air-assisted emptying system using (inset) single conveyor below main duct. (Titmuss)

Floor stores can be emptied by the 'air-sweep' method by use of suitably louvred ducts in combination with a horizontal conveyor situated below the main duct, or a pair of conveyors at each side of it. The operation inevitably creates a great deal of dust in the store, but there is usually no reason why anyone should work in the store during emptying or transfer. When such emptying facilities are provided it is usual to employ a conveyor and thrower for filling the store, and to link the filling and emptying systems so that grain can easily be turned after drying (Fig. 18.18).

For any system of drying grain in bulk, the choice of a suitable ventilating fan needs careful study. The main types used are (a) centrifugal, and (b) dual-stage axial-flow. Both types have advantages for particular kinds of installation, and sound technical advice should be obtained on this and on many others aspects of planning comprehensive installations.



Fig. 18.19 Telescopic boom four-wheel-drive handling vehicle with grain pusher on extension frame used for high loading and levelling on a flat-surface drying floor. (Sanderson)

Cooling bulk grain

The need for cooling bulk grain to avoid the effects of convection currents which can redistribute moisture has already been mentioned. In addition there is the danger of trouble from multiplication of such pests as saw-tooth grain beetles if the grain temperature remains above 16–18°C (60–65°F). Natural cooling in unventilated bins takes place only very slowly – typically at a rate of 0.55°C (1°F) per 4 to 7 days where the initial grain temperature is about 27°C (80°F). On the other hand, use of a very little forced ventilation with atmospheric air will quickly bring temperatures down to the safe level. The amount of air needed depends on a variety of circumstances: 0.01 m³/s (20 ft³/min) per tonne will usually pull temperature down from 27°C to 18°C (80°F to 65°F) in about 3 days, and air-flows as low as 0.003 m³/s (6 ft³/min) per tonne may be suitable where initial temperature is normally not excessive.

Some installations incorporate automatic controls which ensure that the cooling equipment operates only when conditions are suitable.

Cleaning and turning

Dirty samples of grain should always be cleaned before being put into storage silos. Green material in the grain often collects in dense pockets in part of the silo, and these pockets may fail to dry out and may set up heating after ventilation ceases. For this reason it is always advisable to turn grain that has been dried from a high moisture content. One turning soon after drying is complete should be adequate to redistribute any damp patches.

Choice of a grain drier

Choice of a drier involves consideration of the climate of the area, the quantity to be harvested and combine harvester capacity, since these all influence aims regarding moisture content of the grain. Choice also depends on the amount of capital available, and on whether long-term grain storage is required, as well as on such associated problems as grass or hay drying and feed preparation.

Continuous or automatic batch grain driers are usually needed where the quantity to be dried is substantial, and

where a fairly large amount of moisture normally has to be removed. Most continuous farm driers are rated at throughputs of from 5 to 10 tonnes per hour, for a reduction of moisture content from 21 to 15% at a hot air temperature of 66°C (150°F). Larger machines, up to 16 tonnes per hour, are also available. Throughputs are lower at the lower drying temperatures needed for dealing with corn for seed or malting. Nevertheless, a drier with a rating of 5 tonnes per hour should be easily capable of handling 250 tonnes a week, and is adequate for fairly large farms, except in the wettest areas, where much of the grain may need double drying. The capacity of a continuous drier need not be equal to the maximum threshing capacity of the combines. When the grain is wet the combine will always work short hours, and if necessary the drier can work extra time in order to keep pace. It is essential, where a small continuous drier is used in conjunction with tank-type combines, to provide adequate 'pre-drying' bulk storage, so that the combines are not held up by the drier. As a general rule, a drier with a rated hourly capacity equal to about half of the normal overall hourly combine capacity should be adequate without working throughout the night.

Automatic batch driers are available in sizes capable of dealing with from about 50 to 150 tonnes daily. The water-evaporative capacity of a typical ventilated bin plant or floor drier is small, but is partly made up for by continuous operation. In general, however, bulk driers are not the most suitable for farms where a large amount of grain is regularly harvested at moisture contents of over about 21%.

Grain drier layouts

With many plants incorporating bin storage it is necessary to arrange for complete flexibility to permit the grain to be passed through one or more of the following operations: (a) drying, (b) cleaning, (c) storing in silo, (d) removing from silo, (e) passing to feed preparing plant, (f) sacking off or delivering in bulk for sale. Handling grain in bulk leads to considerable economy in labour and is normal practice. It is therefore often necessary to consider the provision of arrangements for the rapid loading of some 20–30 tonnes of grain in bulk, and this will involve either a high-capacity conveying system or provision of an elevated self-emptying hopper which can be

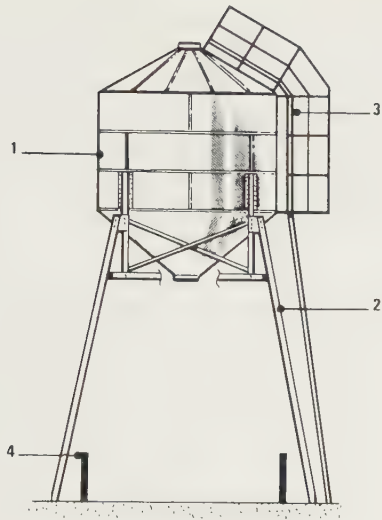


Fig. 18.20 An 11 ft diameter grain outloading bin designed for easy transport to site fully assembled with legs folded. 1 Capacity 492 to 1205 ft³, 2 Foldable legs, 3 Safe access, 4 Traffic barrier. (Rowlands)

filled before the bulk transport vehicle arrives. All this involves careful planning to ensure that the best advantage is taken of the abilities of the machines and of any differences in levels, so that the corn can be efficiently handled with the minimum use of mechanical equipment.

Grain conveying equipment

It must be borne in mind that the conveying equipment at typical farm plants is little used compared with that in provender mills, so it is necessary to keep expenditure on it within reasonable limits. Pneumatic conveyors have advantages in being completely self-cleaning and in being adaptable to irregular layouts. Disadvantages are a rather high power requirement, low output and sometimes excessive dust and noise. Modern conveyors employ an auger or a rotary valve rather than a simple venturi to inject the grain into the air stream. Air speed for grain has to be in the region of 21 m/s (4200 ft/min), and pressure is usually 20 in w.g. (50 mbar) upwards. Where sufficient power is available, throughput is closely related to pipe size.

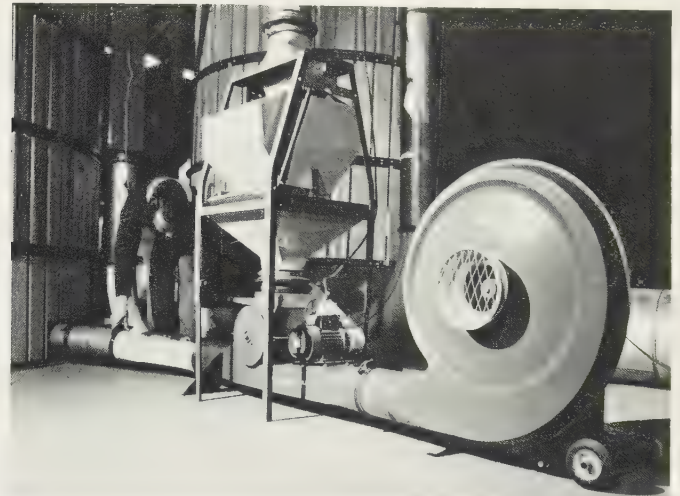


Fig. 18.21 Pneumatic grain conveyor with motor-driven feed inlet beneath automatic weigher. (Kongsilde)

Combined sucker — blowers tend to be rather expensive because it is essential to use a well engineered rotary valve mechanism to transfer the grain from the suction to pressure side, and the fan must be of a precision-made type in order to provide the very high pressure difference that is essential between the suction and pressure sections. For example, a typical high-output conveyor may operate at about 90 in w.g. (225 mbar). Throughput and power requirement do not compare well with mechanical conveyors, so the pneumatic type is only generally used where a straight run cannot be obtained, or where the inlet has to be moved very often, as in emptying a large flat-bottomed bin. Bucket elevators are generally most satisfactory for straightforward vertical lifts, but portable augers or scraper — conveyors which work at an angle may be preferable in some layouts. Where layouts are well-planned and regular, a combination of bucket elevators and horizontal mechanical conveyors may be most satisfactory. One of the simplest and cheapest types of horizontal conveyor is the chain-and-flight type.

Capacities up to any real need are obtainable, and the conveyors can work over the distances normally required in farm plants. A useful horizontal conveyor for high capacities is the endless-belt type. Some employ simple ploughs to remove the grain at intermediate points, while others use a more complex mechanism.

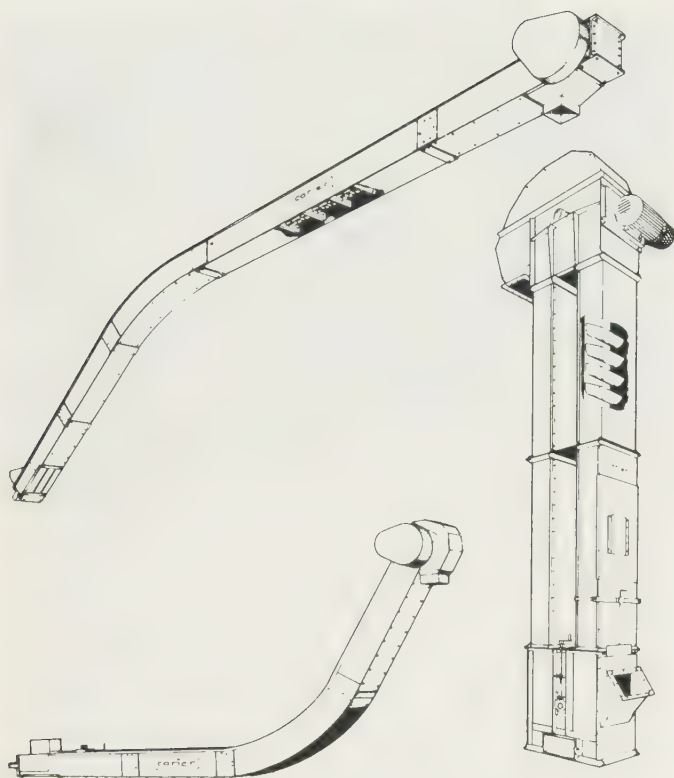


Fig. 18.22 *Left*: chain-and-flight elevator-conveyors. *Right*: bucket elevator showing head, buckets, inspection slide and adjustment (inlet aperture and belt tension) at boot. (Carier)

A very useful type of general-purpose conveyor for movement of grain at an angle is the high-speed auger. Small sizes are usually driven by a light electric motor mounted at the top, and in lengths up to about 4.5 m (15 ft) they are easily moved by one man. Longer trolley-mounted augers are usually shaft-driven by a centrally mounted motor. These are ideal equipment for filling isolated outdoor silos of medium height, since no support is required from the silo itself. For isolated high silos, pneumatic conveying or a forage-type blower is generally used.

For handling grain in a flat store some large-diameter augers can be fitted with a sweep collector. This can be used to receive grain from the trailers when the store is being filled, but its main purpose is to assist in loading grain from the store into bulk transport vehicles. Some

machines use rubber sweep blades which will leave a smooth floor perfectly clean. It is an advantage to have an effective method of pushing the machine into the heap of grain in order to keep it working at full capacity. The usual method is by means of a lever and ratchet mechanism working on a weight-carrying wheel, but some machines are power-driven into the heap by means of reduction gearing.

Unloading of floor stores employing soundly constructed above-ground metal lateral ducts is facilitated by use of an endless-chain rubber-flighted conveyor specially designed for the purpose (e.g. Fyson 'Alligator'). Hydraulic control of slew and angle of inclination, and a lower guard rail which can be allowed to rest lightly on the nearest duct, allow the grain to be cleared from above it so that the duct can be dismantled and removed to allow loading out to continue.

Other special-purpose store unloaders suitable for flat floors include a type with an inclined double chain-and-flight elevator and a sweep auger which can be driven into the heap by a tiller-steered support wheel driven by a 0.75 kW motor (e.g. Parmiter). For loading floor stores, grain throwers may be used, and if handled with care they can result in even filling without any hand shovelling. Their chief disadvantage is the creation of a dusty atmosphere, causing bad working conditions.

For emptying flat-bottomed circular silos, sweep augers of various types are available. Where sweep augers are to be used, a stationary horizontal auger which can be withdrawn and used in any silo draws the grain from an opening in the centre of the silo floor. This horizontal auger may lie beneath a ventilated floor, or in a covered trench just below floor level. The sweep auger is not used until grain ceases to flow by gravity into the foot of the stationary auger. At this point the sweep auger is set in motion, and it gradually moves round the silo, bringing the grain to the centre, where it is picked up by the stationary auger. Sweep augers may be laid in each silo before filling, or may be designed to be introduced and connected up only after the grain no longer flows through the central opening.

A type of auger designed for conveying other than in a straight line employs a bevel gear drive to make up to three right-angle turns (e.g. Devayor). Such conveyors are used mainly for handling stock feed.

Though augers are usually driven by electric motor or sometimes by internal-combustion engine, they may also

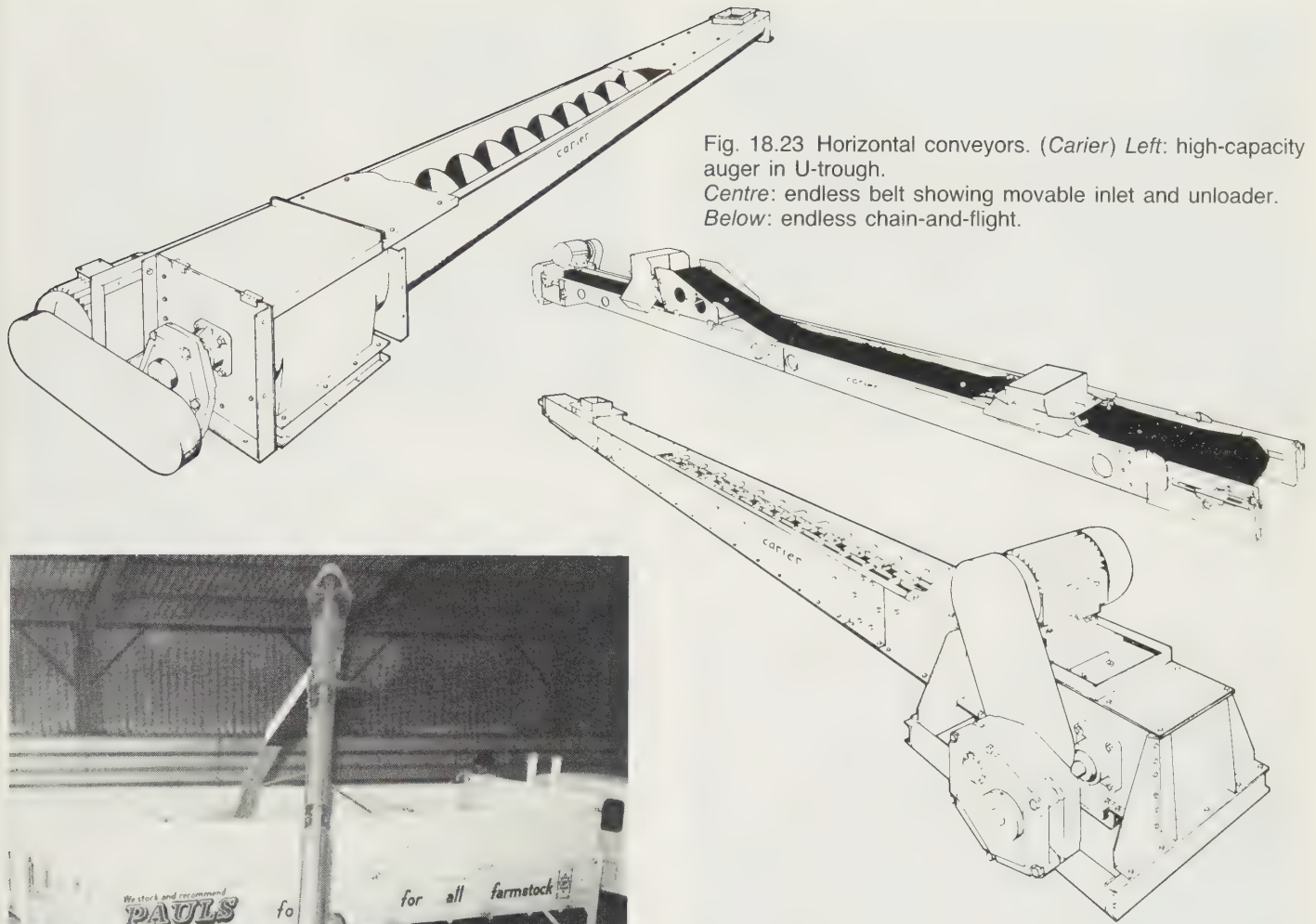


Fig. 18.23 Horizontal conveyors. (*Carier*) Left: high-capacity auger in U-trough.

Centre: endless belt showing movable inlet and unloader.
Below: endless chain-and-flight.



Fig. 18.24 Sweep auger used for loading grain into bulk transport vehicle. (*Ardleigh Swift*)

be driven by a hydraulic motor directly coupled to the shaft, and powered from a tractor's hydraulic system via flexible pipes. Such mobile augers may be used for handling fertilisers or slurry, as well as grain. Typical operating speeds are 1100–1200 rpm and the power requirement is 2.2 to 3 kW (3–4 hp).

Automatic weighers

Grain weighing needs on many farms include recording weights and moisture contents of individual loads from



Fig. 18.25 Grain collector with endless rubber belt and flaps coupled to endless-belt elevator for lorry loading. The collector incorporates hydraulic-powered elevation and slewing, and is able to work effectively where well designed above-floor ducts are used. (Fyson 'Alligator')

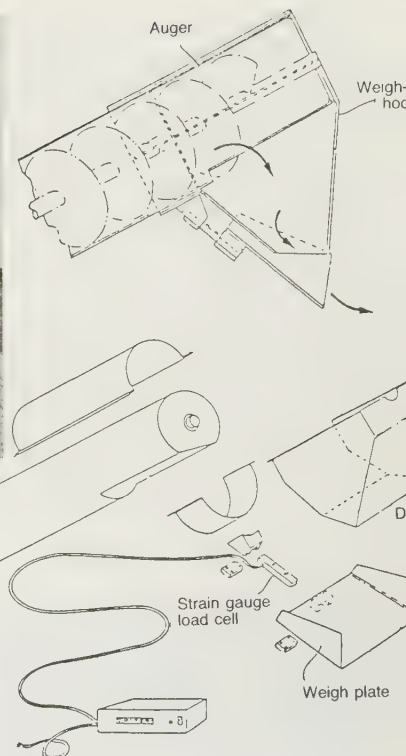


Fig. 18.27 'Yield-per-field' grain weigher with sketches indicating position of deflector hood, weigh plate and strain gauge load cell. (Griffith Elder)



Fig. 18.26 Mast-type rough-terrain fork-lift with grain bucket loading high-sided road transport vehicle. (Sanderson)

combine harvesters to provide information on yields of individual fields, and weights of bulk loads delivered off the farm by road transport. In addition there may be need to weigh batches used in home preparation of stock feed, where low-speed conveying systems may be employed. The main trend is towards use of strain gauges in conjunction with electronic averaging and digital display or recording. The aim is usually a reliable approximation rather than a certifiable weight for trade purposes.

Grain from a combine harvester can be weighed in the field either on its way to the grain tank (e.g. Claydon 'Yield O'Meter') or on delivery to the transport vehicle (e.g. Griffith-Elder 'Yield per Field'). The latter consists of a weigh head attached to the end of the delivery auger, and a microprocessor-assisted control box (in the cab) which adjusts the figures for grain moisture contents, normally registered at the store. Weighing principle is a load cell with strain gauges which sense the bending of a



Fig. 18.28 Filling a high-moisture grain store via a tipping trailer and impeller/pneumatic silo filler.

metal bar. User experience shows that results can be accurate and valuable for both cereals and rape, and that the extra time taken can be minimal.

The chief practical alternative to on-combine weighing for field yield estimates is by weighing incoming bulk loads at the buildings. Some large-scale farms use completely static weigh platforms, or electronic machines of similar cost which can satisfy official trade standard tests. At the other end of the scale individual wheel weighers can produce reasonably accurate results, but with some operational difficulty. In between there are moderately priced electronic mobile weigh platforms incorporating at least two well protected strain gauge weigh pads which can suit many users. The smallest of these, with two weigh pads and microprocessor control unit, can weigh individual axles in succession, at net axle weights up to 10 tonnes each. The microprocessor provides gross, tare

and net weights with totals for two (or more) axles, and the records can be automatically printed with the necessary vehicle identifications (e.g. Griffith-Elder). Larger machines with 4, 6 or 8 weigh pads and total capacity up to 40 tonnes are available. Weigh platforms of this general type are usually best installed at a carefully chosen point on reasonably level concrete well above surface water level, with suitable low-angle ramps at each end.

Other types of electronic automatic weighers increasingly used on stock farms include both small-batch machines with self-emptying hoppers for weighing cereals before grinding, and continuous-flow low-throughput belt weighers for feeds such as short-chopped silage delivered from towers.

Airtight storage of high moisture grain

Grain intended for stock feed can be effectively stored in containers which can be maintained substantially airtight. Grain of over 30% moisture content can be stored in this way, though in practice storage at such high moisture contents is generally inadvisable owing to the greater difficulty of handling, and rapid deterioration of the grain after removal from storage. The essential factor in 'airtight' storage is exclusion of oxygen. This prevents the development of moulds and micro-organisms which cause moist grain to heat in the presence of air. Some chemical changes take place in moist stored grain, owing to the activity of yeasts. The grain takes on a smell comparable with that

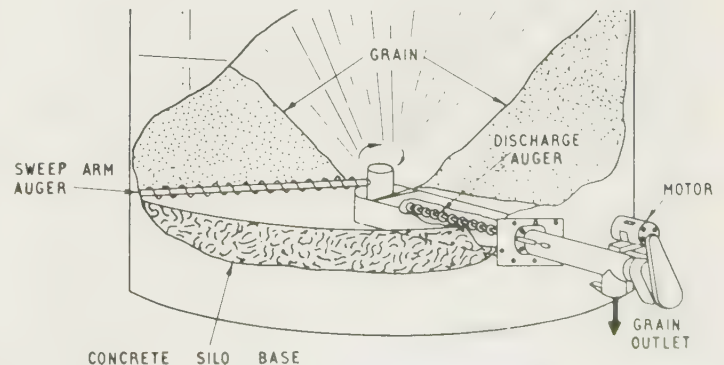


Fig. 18.29 Sweep auger used to remove grain from sealed silo used for airtight storage of high-moisture grain. ('Harvestore')

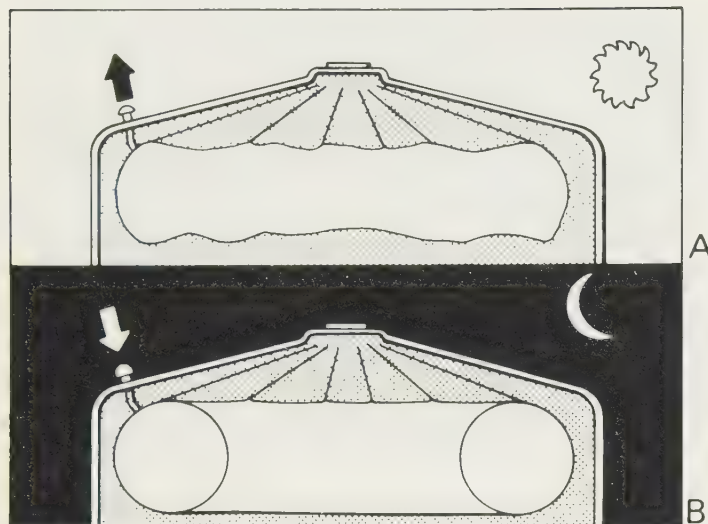


Fig. 18.30 Action of breather bag in a sealed silo. ('Harvestore')

A Bag collapses as temperature rises, B Air enters bag as temperature falls.

of brewers' grains, and becomes unsuitable for purposes other than stock feeding. The feeding value of the grain is not, however, impaired, provided that the store remains substantially airtight.

The main kinds of store used are metal silos which can be sealed, apart from provision of relief valves; flexible silos made of butyl rubber which can be sealed; and unsealed silos from which air can be effectively excluded by means of an impermeable sheet until rapid and regular use of the grain begins. For ease of handling, grain kept in sealed silos should be clean and not over about 25% moisture content. With unsealed towers which use a sweep-arm top unloader, somewhat higher moisture contents need cause no difficulty.

Airtight silos

A common method of construction is by the use of bolted metal plates, protected from corrosion by fused glass or by galvanising. Provision of pressure relief valves is essential to allow for the expansion and contraction of the silo atmosphere owing to ambient temperature changes. The amount of gaseous exchange is highest with empty or

nearly empty silos, and this is one of the reasons why deterioration of grain can become serious if a little grain is left in a silo in spring or summer. To minimise gaseous exchanges, one manufacturer provides a plastic breather bag, so arranged that on cooling, atmospheric air first enters and inflates the breather bag, and only passes through the relief valve into the main silo air space after the breather bag is full, and the vacuum outside the walls of the bag exceeds the relief valve setting. Such devices are useful if grain is to be fed from the silo for an appreciable period during spring and summer. In winter ambient temperature differences are smaller, and the cooler air has less tendency to stimulate microbial activity.

Unsealed silos

The main use of unsealed tower silos is for large stock-keeping installations where the moist grain is used up at a rate of at least 75 mm (3 in) of silo height per day, and the whole silo is emptied before the onset of warm weather in spring. In these circumstances the simplicity of the unsealed tower is attractive, and the main problem is to provide an effective top seal for the period between harvest and the beginning of emptying.

One satisfactory method is to cover the top with at least 150 mm (6 in) of any convenient material to absorb condensation moisture, e.g. chopped straw, and to cover this absorbent layer with a heavy gauge polythene sheet, well tucked down at the edges.

Flexible sealed silos

Silos may be constructed of butyl rubber or similar flexible materials, but good handling systems for filling and emptying them are not easily arranged. The silos themselves are relatively cheap, and the elasticity of the container walls makes it possible to accommodate expansion and contraction of the silo atmosphere without the use of relief valves. It should, however, be reckoned that the trouble-free useful life is likely to be much shorter than that of rigid-walled silos.

Loading and unloading equipment for moist grain

Many moist grain silos are easily filled by mobile grain-handling equipment, especially augers. The main problem

is the difficulty of reaching the tops of high towers, especially those 12 m (40 ft) high or more. For these, the most convenient method is usually by means of a forage blower of the normal impeller type. These can effectively fill towers 18 m (60 ft) high if properly installed and driven at the right speed. Filling rate tends to fall off with increasing height, and there is some grain damage, but this is not usually important except in so far as it may cause emptying difficulties.

For intermediate heights, trolley-mounted augers and chain-and-flight mobile elevators may be used. The latter can be particularly effective for heights up to about 7.6 m (25 ft). If grain which is contaminated with chaff or weeds is to be unloaded subsequently by simple augers, it is advisable to pre-clean it before ensiling. It is essential to seal the silo during breaks in the harvest, in order to avoid any unnecessary heating. Grain temperature should not normally rise above about 26–32°C (80–90°F).

For unloading, one of the most effective methods is use of a sweep-arm auger which runs in the bottom of the silo, and delivers the grain to a sealed auger running in a trough from the centre to the outside of the silo base. This transfer auger is used alone until grain no longer flows by gravity to the centre of the silo. The sweep arm is then put in gear and gradually works its way round the silo, leaving only a thin, uniform layer of grain to be swept to the central collecting bowl. Much simpler methods are widely used, but require more shovelling. One of the most common methods is use of a simple sealed auger which can be pushed into any one of three open-ended tubes arranged fan-shaped on the flat silo base. Where a clean grain of not more than about 21% mc is ensiled, a conical base can be almost completely emptied by auger.

One of the disadvantages of imperfect unloading systems is that there is a risk that someone will enter the silo without taking the precautions necessary to ensure that there is sufficient oxygen in the silo. The danger of suffocation cannot be over-emphasised.

Use of propionic acid for moist grain preservation

Chemicals can be used to sterilise grain and so prevent the development of moulds and bacteria. Experience shows that about 0.8% of propionic acid applied to grain at 18–20% mc can effectively prevent deterioration for a very long period. One of the chief advantages of using propionic acid for moist grain preservation is that silos do not need to be airtight. An additional advantage is that there is less danger of the grain going mouldy if used slowly during the following spring, and that chemically preserved grain has a longer 'shelf-life', both before and after crushing or other preparation treatment. For best results it is necessary to use application equipment that ensures good mixing of the additive with the grain, and avoids handling dangers.

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Equipment for Livestock Husbandry

Some of the most important equipment used in mechanised stock farming is dealt with in other chapters: for example, equipment for feeding silage is described in Chapter 12, equipment for manure handling in Chapter 8 and feed preparation equipment in Chapter 17. This chapter deals mainly with equipment for feeding materials other than those derived from forage crops, and with a few specialised items which do not fit logically elsewhere. Milking is covered in Chapter 20, and environment control in stock buildings in Chapter 23.

Equipment for mechanised stock-feeding

There are many ways of reducing the labour required for stock-feeding, and important developments are taking place in the feeding of poultry, pigs and cattle.

When rations have been mixed, it is often unnecessary to use bags for transporting the food from the milling and mixing plant to the stock. On some farms it can be conveniently transferred in hand trucks, and on others stillages or specialised bulk-handling containers may be used. One type of bulk-feed truck has a V-shaped hopper and incorporates augers for delivering the food either to a container at the point of use, or directly to the mangers.

Bulk delivery vehicles

There is little doubt that use of such bulk-handling equipment will steadily increase. Features in some designs include a hydraulically extended delivery auger capable of filling quite high storage hoppers.

When a bulk-handling vehicle is used for feeding direct into mangers or self-feed hoppers, there are several additional features which may be useful. The machine may



Fig. 19.1 Bulk concentrate conveyor with auger delivery for filling high bulk hoppers. (Rowlands)

include two compartments, one designed to hold the home-grown part of the ration, e.g. rolled barley, while the other is used for a purchased balancer. It is then useful if the balancer can be metered out in a chosen proportion with the rest of the feed, so that different rations may be fed from the same two ingredients to groups of stock having different needs. Vehicles for complete-diet feeding, with ability to handle mixtures of chopped forage and concentrate, and also to weigh ingredients as they are filled into the hopper are dealt with in Chapter 12.

Concentrate feed conveyors

There is a wide choice of auger and endless-chain conveyors for delivering meal, rolled barley, dairy nuts, etc., to dispensing hoppers. Where practicable it is best to arrange augers to have a straight run, with a minimum of bends. Right-angle bends can, however, be provided to enable a single motor to fill two lines of hoppers by making two 90° bends at the far end. Well designed feed chains can be made to run round bends without much complication. The chains usually run round pulleys at the corners. The trough may be of wood or steel. Hoppers are normally filled through an opening in the bottom of the conveyor trough, and filling is progressive, the conveyor being stopped by means of a pressure switch when the last hopper is full. Applications include pig feeding,

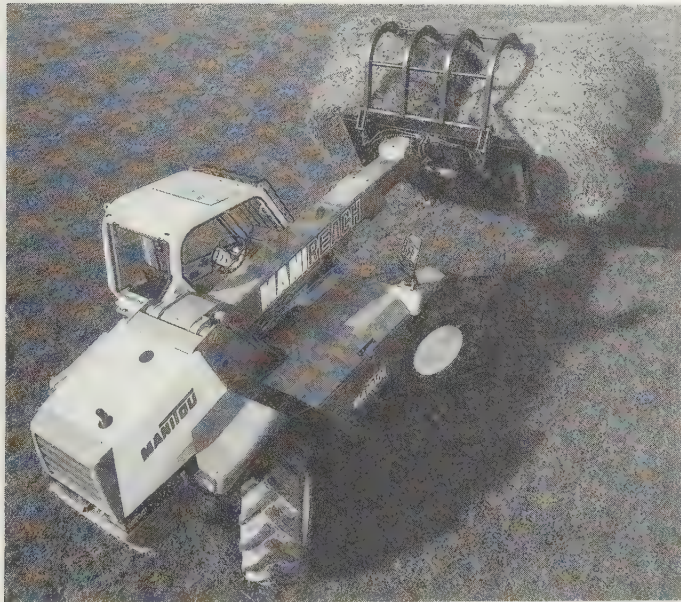


Fig. 19.2 The Manireach 2600 telescopic loader has a low profile with boom lowered (2.35 m (8 ft)) minimum height, which enables it to work in stock buildings that are inaccessible to some other handlers with similar power choice (90 hp or 104 turbocharged). Lift height 5.8 m (19 ft) and forward reach 3.35 m (11 ft) are normal, and steering features the now usual front wheel only for long runs, crab for sideways moves, and opposite for tight turns at low speed as illustrated. Safety and comfort of the driver, ease of operation and quiet ROPS cab are given deserved attention. (*Manitou Manireach 2600*)

poultry feeding and filling of the feed dispensers in milking parlours.

Medium-pressure small-bore pneumatic conveyors, briefly described in Chapter 21, and open-centre flexible augers, can be used for delivering concentrate from a central store to widely scattered bulk hoppers, or from bulk hoppers to dispensers within stock buildings.

Time switches and other forms of automatic control are increasingly used to reduce labour needs, to take advantage of off-peak power tariff and to restrict damage from failure during unattended operation of conveyors.

Feed dispensers for milking parlours

With the development of use of milking parlours it has become normal practice to feed the concentrate ration in the parlour, where the amount given can easily be related to milk yield. This feeding takes place twice daily every day, so it is worthwhile to provide labour-saving equipment to ensure that the work is done easily and accurately.

With the modern trend towards two-level parlours, the manger is usually some distance from the operator, so to save unnecessary walking the equipment is usually operated from the pit.

The hoppers above the dispensing mechanism are usually filled either from a loft above the parlour or by an auger or chain-and-flight conveyor. Where a conveyor is used the hoppers are progressively filled, and the conveyor is automatically stopped by a pressure switch when the last one has been replenished.

Feed dispenser mechanisms

Most concentrate dispensers operate on volumetric rather than a weight basis. This obviously makes for design simplification but can also lead to inaccurate feeding if changes in the bulk density of the material being fed are not taken into account.

Semi-automatic systems

Semi-automatic systems lighten physical work and place the controls where the operator can easily reach them. The feeders are operated electrically or electro-pneumatically, and usually consist of augers or vibrating pans. The amount to be fed has to be set for each individual



Fig. 19.3 Open-centre flexible auger used to convey concentrate from bulk hopper to dispensers in livestock buildings (EB). Distance up to 80 m (250 ft); rate up to 1 tonne/h.

manger on a central control unit; this also incorporates the feed button which initiates feeding after all controls have been set. In a typical electro-pneumatic system (Fig. 19.4) the feed delivery device is an auger, driven by a piston and cylinder assembly. The piston is operated by a vacuum, which is applied through a relay valve operated by a 12–15 volt d.c. source through a central control box calibrated in 1–10 units for each feed hopper. Turning the control knob winds the spring of a timer fitted with a multi-lobe cam. The timer closes the micro-switch connected to the relay valves the number of times corresponding to the controller setting. Length of the piston travel is adjustable, and determines the quantity delivered at each stroke.

A similar system makes use of a hinged plate dispenser.

Choice of system

Some manufacturers offer a choice of at least three degrees of mechanisation and automation which may be distinguished as:

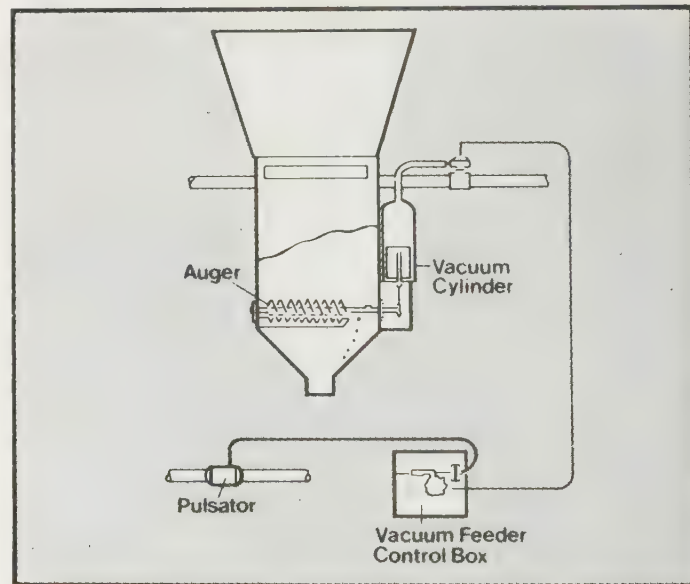
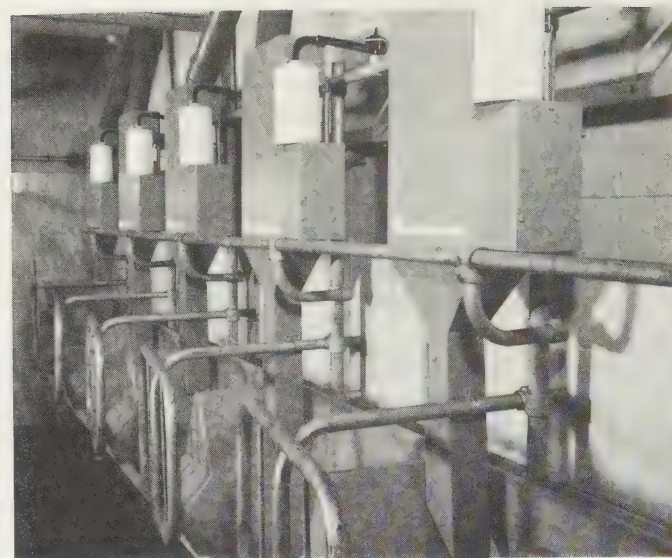


Fig. 19.4 Pneumatically operated pre-set feeders for dairy parlour. Diagram indicates general layout of feeder, its control, and the vacuum cylinders which operate the feed augers. (Alfa-Laval)

(1) *Individual dialling of feed*: The operator dials the amount to be fed as described under semi-automatic systems. He may be assisted by coloured bands attached to the animals. When the 'feed' button is pressed, the amount



Fig. 19.5 Gravimetric feed dispensers in a herringbone parlour. (*Fullwood and Bland*)

dispensed at each stall is determined by the dialling (e.g. 'Rationmaster').

(2) *'Memory Bank' or 'Computafeed'*: As the cows enter the parlour, the operator enters the cow number corresponding to each stall on a parlour key-board that is linked to a computer with stored information concerning the feed requirement of each animal. When all the stalls are full, pressing the feed button feeds each cow according to the latest stored information.

(3) *Automatic feeding*: The system is similar to (2) above, but cow recognition is automatic. Each cow wears a neckband with transponder attached; this provides an individual signal notifying cow number to the computer when the cow is in place in the stall. Procedure for feeding is then simply to press the feed button, (as in final stage of (2)).

Favoured mechanisms for dispensing by power include by auger and by vibrated tray. Both types are normally controlled on a time basis, and both are susceptible to the usual degree of error dependent on changes in bulk density of the feed. In a typical auger system (e.g. Alfa Laval vacuum and 'Memory' feeders) the auger is driven by a vacuum-operated piston. In a typical vibrated tray system (e.g. Fullwood 'Rationmaster') the main motive power is the vacuum supply of the milking installation. This is employed to cause a diaphragm to vibrate at about 400 cycles/min by a pulsed interruption of the low-voltage d.c. supply to a solenoid which causes one side of the diaphragm to be alternately subjected to vacuum and atmospheric pressure.

Gravimetric dispensers

In a gravimetric system (e.g. Fullwood 'Gravimatic') the feed from the 'Rationmaster' tray is not delivered directly to the manger, but instead to a container pivotally attached to one end of a weighing beam which has a counter-weight corresponding to the desired weight of feed to be dispensed in one weigh cycle. When the set weight is

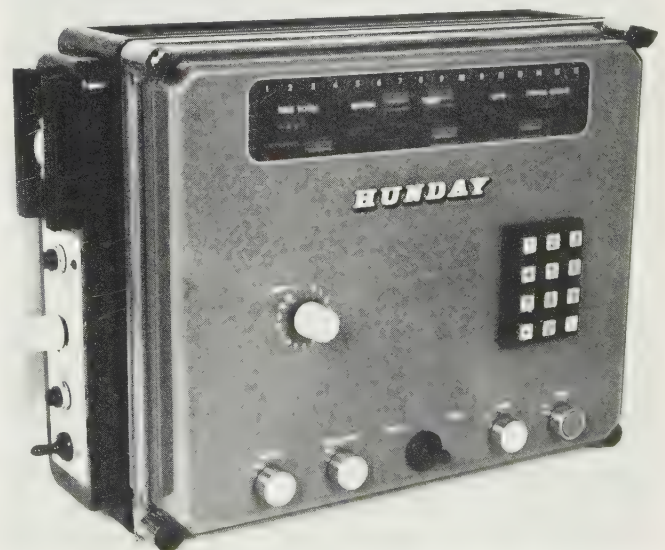


Fig. 19.6 Operator's console for milking parlour 'Memory bank' feed system. (*Hunday*)

In the centre is the three-digit cow number key-board. Upper windows show total fed, ration fed, cow number and cow total. Selector knob to left permits manual ration control.



Fig. 19.7 Rationed group feeding: pre-set amounts of concentrate are fed to the dairy herd in cubicles by means of a flexible-auger conveying system. (EB)

reached, movement of the weigh beam shuts off the feed by stopping vibration of the tray; the weigh pan tips the contents into the manger, and the feed cycle resumes unless the controller closes it down because the required ration has been delivered.

If sophisticated programmed feed systems are to pay for themselves the required ration programme for each animal has to be updated by the herd manager at regular intervals. The computer can provide information on the total amount of concentrate fed to the herd as a regular check against total yield.

Some modern installations provide for automatic weighing and recording of yield from individual animals by means of electronic weighers fitted to the milk jars, or milk meters fitted with an electronic pulse signal.

Out-of-parlour concentrate feeders

High-yielding cows which need to eat large amounts of concentrate to achieve their full potential can benefit by

being able to take much of this ration outside the parlour. Out-of-parlour feeders consist of the required number of dispensers, mangers and stalls located where they are accessible to the high-yielders between milkings. The simplest type requires only a simple trigger mechanism to operate the dispenser: cows wearing a chain can get extra feed at any time. Independent studies show that this type can fail to achieve its objective because some cows entitled to feed do not use the feeder, while others take more than can be economic.

Programmable out-of-parlour feeders

A unit of typical design consists of a controller capable of operating up to eight feeders, which between them can handle up to 255 cows. Units of feed may be pre-set between 0 and 1 kg, and quantity dispensed per animal daily can range from 1 to 99 units. Rate of dispensing is in effect one unit per $1\frac{1}{2}$ min, because there is a time lapse of this length between deliveries. The day is divided into 6-hour periods. Up to a quarter of the daily allowance



Fig. 19.8 Automatic controlled feeding of concentrate to cattle in inaccessible straw yards. (EB)
Each cylindrical feeder can deliver up to 40 kg (88 lb). Dispensers are supplied by open-centre flexible auger.

can be taken in the first 6 hours: a third of the remainder during the second period: half of the rest in the third, and the remainder during the last. The control unit can at any time during the next day display the amount taken by each cow during 24 hours and the total of allocated feed not eaten by the herd.

With any type of out-of-parlour feeder it is necessary to provide guard rails and to install the units where intimidation is least likely. A few cows have to be trained to use the feeders.

Automatic calf feeders

Automatic calf feeders can be of several types. Most are designed to enable calves to feed *ad lib* on a suitable mix of warmed water and a proprietary milk powder, using a teat with non-return valve, supplied through a plastic pipe. A machine suitable for large-scale use can feed up to 70 calves which may be housed in four pens, each pen

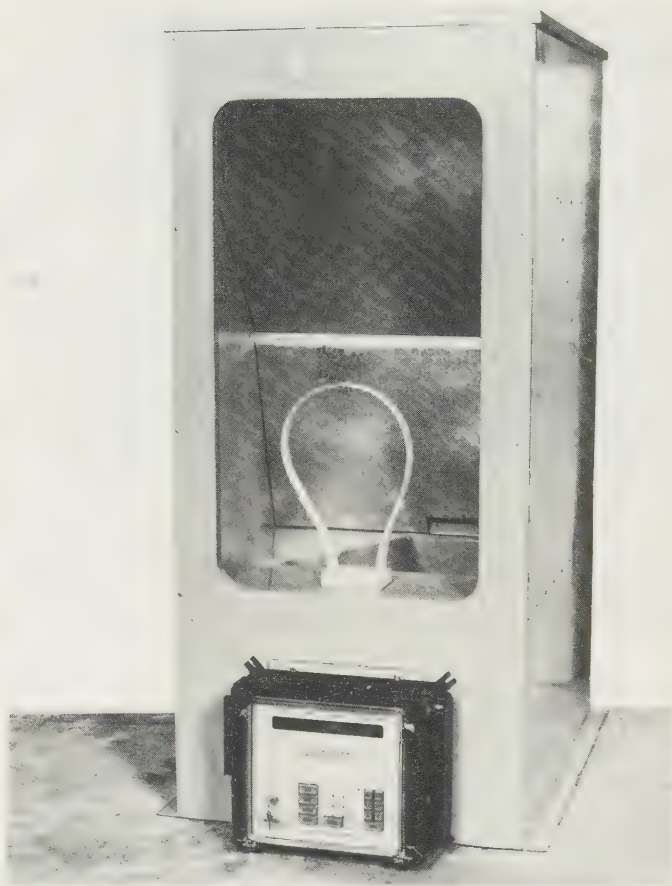


Fig. 19.9 Programmable out-of-parlour feeder. Illustration shows feed stall with dispenser, cow collar with transponder attached, and central controller which can handle several feeders. (Hunday)

fitted with a single teat (Fig. 19.10). The machine houses a large powder hopper and well-lagged hot water tank. For each batch the adjusted quantity of powder is augered into a fixed quantity (0.5 litre) of water, which is transferred automatically from the hot tank. The mix is stirred and has its temperature maintained by a small supplementary heater. Finger-tip controls on a modern electronic console provide for adjustment of concentration of the mix and temperature regulation. Total power load is 3.1 kW.

A refinement providing control of feed to individual calves is most likely to appeal to dairy farmers who

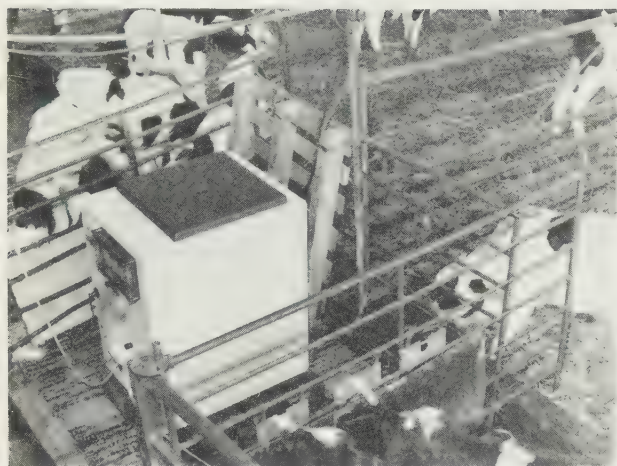


Fig. 19.10 Automatic calf feeder arranged with plastic feed lines to supply teats in up to four pens. Two lines are shown feeding the pen in foreground, and two lead to a second pen. (Volac)

already operate out-of-parlour feeders with transponder control. The calf-feeder stations can be computer controlled through transponders worn on a neckband, and permitting adjustment of feed programmes to individual calf needs (e.g. Alfa-Laval).

Another type of equipment has a line of feeding teats which are presented for feeding at regular intervals, and can be automatically washed and disinfected at the end of the feed. Such equipment is used in some countries for feeding many batches of calves, which are moved to the feeding parlour in rotation. A typical unit has a 0.6 kW ($\frac{3}{4}$ hp) circulation pump and a 0.4 kW ($\frac{1}{2}$ hp) compressor to operate the teat-bars where operation is automatic.

Hand-feeding into buckets can be assisted by use of a dispenser that is mobile, or has a long, flexible hose for final delivery. One type with a 225 l (50 gal) tank has a 0.6 kW ($\frac{3}{4}$ hp) centrifugal pump which dispenses at a rate of about 1 litre ($\frac{1}{4}$ gal) per sec.

Feed meters for addition of concentrate supplement

Adjustable feed meters are available for adding a variable proportion of a pelleted feed or a meal to a stream of silage or other bulky feed. The equipment consists essen-

tially of a U-shaped hopper with a horizontal auger which can be set to run at the desired rate by setting variable-speed pulleys or a ratchet mechanism. Additionally, the quantity delivered may be regulated by setting a time switch if desired.

Mechanical pig feeding equipment

Pigs can be mechanically fed in several ways. One of the simplest is use of an auger above the troughs. The auger casing has a number of apertures in the bottom, and these either lead to down-pipes that end just above the floor of the trough, or are situated on top of an inverted-V-shaped feeder. Meal continues to be delivered until the



Fig. 19.11 Dry pig feeders arranged for rationed feeding of meal or pellets on the floor. (EB)

trough is supplied, and the pipe or hopper is full, so preventing further flow through the aperture. The amount fed to individual pens can easily be varied by a simple telescopic device in the down-pipe, which projects into a parallel-sided hopper. The amount fed into the hopper then varies with the distance from the bottom of the telescopic spout to the bottom of the hopper, since no more meal can be discharged after the level of meal in the hopper reaches the bottom of the pipe. Feed dispensers vary considerably. The simplest are an '*ad lib*' type, and these may lead to some over-feeding and waste. Where *ad lib* feeding is practised it is becoming usual to aim at limiting consumption by requiring the pig to do a little work in order to obtain a little meal. For example, it may be necessary to raise a flap, or to rotate a cylindrical dispenser. *Ad lib* feeding is much more common in America than in Britain. For bacon production in Britain the aim is usually to limit feed by using metering dispensers which can be set to deliver a definite and easily adjustable amount at each feed.

One common type of dispenser designed for feeding on the floor consists essentially of a cylindrical hopper with a hinged flap at the bottom. The amount of feed that goes into the hopper is adjusted by means of a simple telescopic device, and the opening of the bottom is done automatically by means of a time clock. All of the feeders in a house operate simultaneously, and this helps to avoid prolonged excitement at feeding time.

Another type of dispenser is designed for trough feeding. The dispenser is of an elongated rectangular shape, designed to spread the feed over a considerable length of trough. Dispensers are filled by an endless chain running in a rectangular metal trough. The hinged bottom of the dispenser is opened by a draw-bar and compressed air system, arranged so that all dispensers are opened simultaneously. At the same time water is sprayed on to the meal in the troughs, and the dispenser bottoms are then closed ready for refilling.

One of the earliest types of automatic rationing pig feeders was a travelling hopper type, designed to run along above the troughs of a piggery with a feeding passage. This type makes use of a travelling hopper which is pulled by an electric winch along the feeding passage, and only delivers meal when its feed roller is rotated by driving pegs fixed above the troughs. The quantity delivered to each pen is easily varied by adjusting the number of drive pegs.

Other types of travelling-hopper feeder employ electronically controlled feed-metering devices in the hopper itself. In the case of a piggery where it is desired to vary the quantity fed to individual pens, the amount delivered can be set by means of adjustable strikers on a rail above the pen. The feed hopper may travel on rails laid on the pen walls, or may be suspended from sliding-door gear. The electricity supply is conveyed to the feeder by a looped cable suspended from a wire above. The control principle is use of a metering auger which is operated for a predetermined time by limit switches.

One of the great advantages of any type of automatic pig feeder is the ease of feeding four times daily, and the fact that the pigs become so accustomed to the regularity of feeding that they become very quiet, and rest most of the time between feeds.

Liquid pig feeding equipment

Wet feeding of pigs has many advantages. The equipment required is extremely simple, and is easily fitted into almost any type of piggery that is equipped with feed troughs. Mixing of the meal and water before pumping makes it practicable to do without a dry feed mixer on farms where pig feeding is the main enterprise.

In a typical installation, a centrifugal pump is used for recirculating the mix to help to secure uniform mixing, and also to deliver to the feed line, the surplus being returned to the tank. The same pump can, if necessary, lift water to fill the mixing tank. For easy and efficient control of these operations, a special full-flow valve may

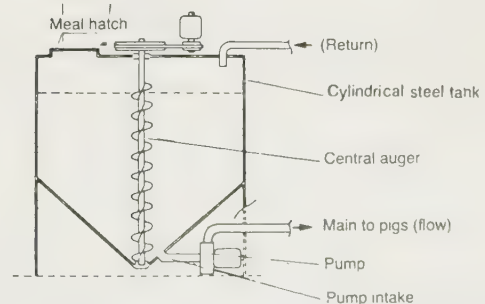


Fig. 19.12 Auger-type liquid feed mixer for pipeline pig feeding.

effectively be used (Fig. 19.13). A large-diameter vertical auger is generally used to secure quick and effective mixing. The normal method of making a mix is first to fill the tank with water, and then to add the meal while both operating the mechanical stirrer and recirculating by using the pump and a loop system. Normal practice is to return the feed pipes to the tank. The feed pipe itself holds about 18 l (4 gal) for each 9 m (30 ft) length of 50 mm (2 in) pipe, and this extra quantity must be allowed for on first filling. After feeding, the pipeline may be washed out by pumping clear water. The washings then remain in the mixer ready for the next feed.

Two-inch BSP pipework is normally used for larger installations, and 1½ in for smaller sizes. The main pipework may be either steel or polythene. A typical range of sizes is from 900 l (200 gal), with 1.5 kW (2 hp) on both the auger and the pump, up to 5625 l (1250 gal), with 5 hp on the mixer and 10 hp on the pump (3.7 and 7.5 kW).

Distribution to the troughs is usually by means of a hand-operated valve, often via a short length of flexible

hose which can deliver to two or more troughs. Rationing can be achieved by timing with a stop watch if desired.

One method of mixing and pumping is by means of compressed air (pumping pressure about 0.4–0.8 bar (6–12 psi)). This has the advantage of avoiding the wear that occurs in any type of hydraulic pump, and fairly rapidly impairs its efficiency. Automatic rationing systems usually depend for efficient operation on securing a uniform mix and on having a pump which operates at a constant rate.

Automatic liquid feeding

A diaphragm valve operated by a solenoid can provide the basis of a system of automatic rationed liquid feeding. Each pen is served by one of the valves, and rationing for each pen is set in a central control box, normally on a time basis. In a typical arrangement, pressing the start button first operates the mixer. The pump first operates for a short period on recirculation, and then feed is pumped along the delivery line. Each pen is then fed in rapid succession for the length of time that has been pre-set.

Research at Silsoe Research Institute has shown that mixtures composed mainly of milled barley and water at ratios of about 1:2½ are easier to pump during the first 15 minutes after mixing than after an hour's soaking. There are also other advantages in continuous mixing systems, e.g. avoiding the need for large mixing tanks, and for breaks to replenish supplies when the mixer tank capacity is not sufficient to feed the whole herd.

Feeding trials indicate that wet feeding, with a water: meal ratio of 2½:1 by weight, gives better results than dry feeding. Some farmers who have switched from dry to wet feeding report appreciable annual savings in feed costs. A disadvantage of automatic systems that feed pens in succession is the undesirable stress caused by the squealing of groups awaiting the feed. The Silsoe Research Institute has adapted a type of canister dispenser used in dry feeding for liquid feeding. The dispensers are all filled to desired levels of weight in succession well before feeding time. The feed is later released from a large number of dispensers simultaneously by a pneumatically operated ram on each which withdraws a conically shaped plug to permit discharge from the bottom. Heavy fractions of the feed soon settle in the dispensers, but are easily flushed out when the plug is withdrawn. The dispensers can

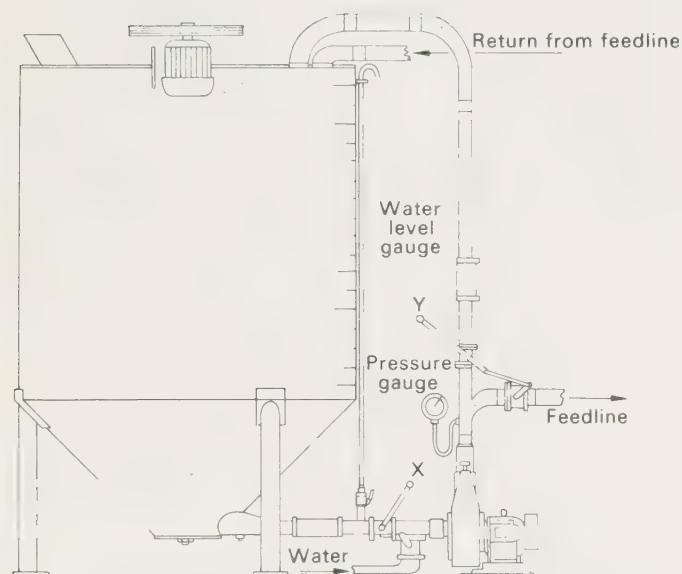


Fig. 19.13 Liquid pig feeder with recirculation. (Reffold)
Valve X provides for (1) water only to pump (2) water and feed to pump (for adding extra water to feed) (3) feed only to pump. Valve Y provides for (1) full recirculation of mix (2) pressure regulation to pipeline (3) full pressure to pipeline.

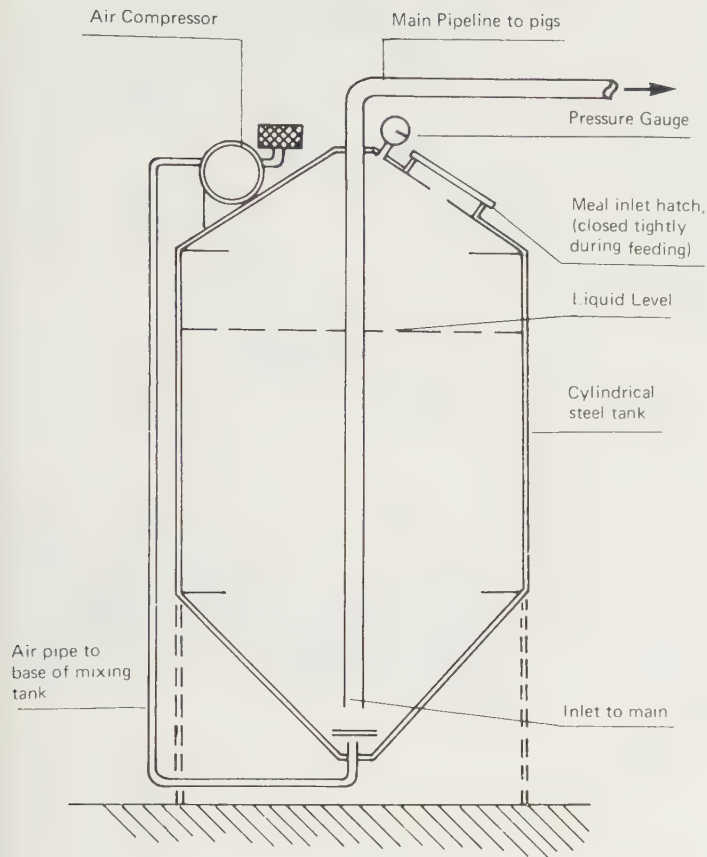


Fig. 19.14 Compressed air mixing and delivery for pipeline pig feeding.

weigh to $\pm 2\%$ of the required weight. Trials have been carried out in both Russia and the USA on feeding moistened meal in a semi-solid form, rather than as a slurry, and the advantages claimed for such a system are avoidance of separation of solids and water, together with accurate metering and low wastage. A compressor is used to force the feed through small-bore pipes. The feed can be delivered by such means over very long distances, e.g. up to 0.8 km ($\frac{1}{2}$ mile). The consistency used is a paste containing about 60% moisture.

Poultry feeders

The mechanical devices available for poultry feeding include simple equipment to assist hand feeding, more

complex mechanical feeders and fully automatic feeders. Devices to assist hand feeding include hoppers which can be pushed along rails to fill the fixed troughs attached to battery cages. Such feeders may be used to fill three troughs at a time, and can provide a reservoir of food large enough to avoid the necessity of feeding at week-ends. They are suited to medium-sized installations, e.g. houses with about 2000 birds. Similar mobile feeders may be electric winch-operated, and control can easily be automated if desired.

Simple conveyor-type mechanical feeders use chain-and-flight conveyors or augers to fill tube feeders in deep litter houses. These operate like the *ad lib* pig feeders already briefly described. The feeders are normally suspended a little above the floor, about four feeders being provided for each 100 birds. An electric anti-roost guard may be provided. In automatic installations the motor operating the conveyor is switched off by pressure switch when the farthest hopper is full.

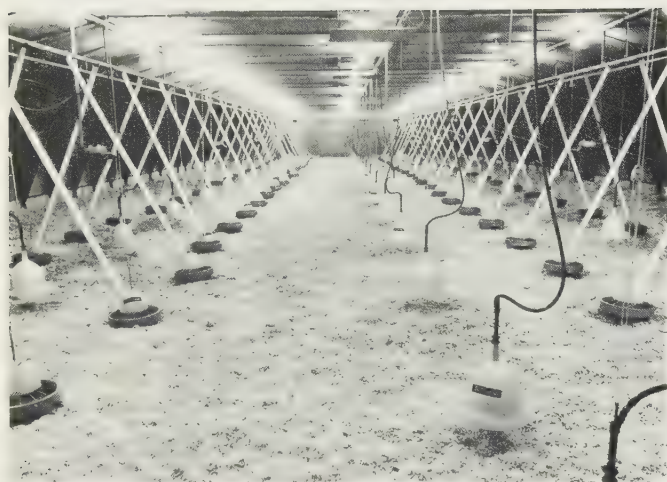
Endless-chain automatic feeders

A typical installation includes an outdoor bulk hopper, from which the feed is augered to the automatic feeder bin inside the poultry building. The feeder usually consists of a very light trough, about 75 mm (3 in) wide, with an endless chain running through it. The feeder trough is usually mounted from the floor, but may be suspended from the roof. The layout must be carefully planned. 300 mm (1 ft) of trough, accessible on both sides, must be provided for a maximum of fourteen adult birds or up to twenty-eight growers.

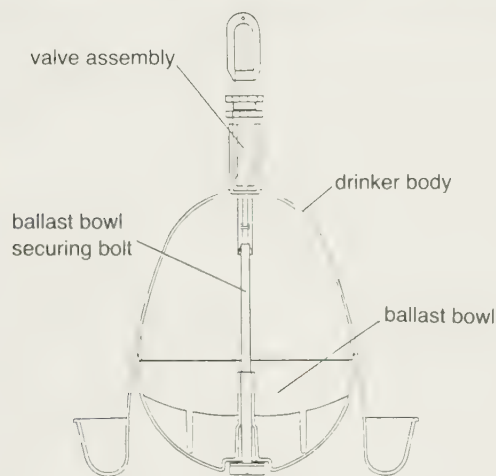
Time switches are normally fitted, and the feeder is usually operated at set intervals during the day. Some farmers arrange for operation before the trough is empty; others run it soon afterwards. As a general rule, food should not be withheld for more than $\frac{1}{2}$ hour, or vice may be encouraged. Intermittent feeding encourages appetite.

Mechanical feeders are unsuitable for very young chicks, so temporary feeding arrangements must be made for the first 10 days or so. The feeder must be adjustable in height, and should be kept at about the height of the fowl's back.

One of the factors to be borne in mind in choosing poultry feeders is that more moving parts tend to lead to more maintenance being needed, and more danger of breakdowns.



(a)



(b)

Fig. 19.15 (a) A large poultry house equipped with tube-type *ad lib* feeders and automatic drinkers. (*Big Dutchman*)
(b) Section of water-ballasted automatic suspended poultry drinking bowl with adjustable valve for setting water depth. Integral hemispherical ballast bowl provides low centre of gravity; moulded stabiliser blades help to minimise spillage. (EB)

For laying batteries there are considerable cost advantages in use of fixed troughs and mobile powered feeders which can deal with several lines of cages. Mobile feeders may be electrically powered or engine driven. Electrically powered machines may be either battery operated or may use a trailing cable. If necessary, delivery

spouts can be made adjustable to suit different trough locations.

A report by the National Institute of Poultry Husbandry shows that many of the non-mechanical conventional tubular feeders are very wasteful of mash. With light breeds, a third of the proprietary makes tested showed over 10% wastage. The best showed 6% wastage. Such losses during the course of a laying year can justify more expensive systems. There was very much less wastage when pellets were used. Even feeders showing 10% loss with mash gave only 1% loss with pellets. The more complex systems are usually winch-suspended to provide easy height adjustment of feed pans, and have an electric-fencer-type guard wire attached above each line to prevent perching.

An important development in mechanised poultry-keeping was the introduction of nipple drinkers in place of water troughs. These have considerable advantages in maintaining a clean supply and avoiding the bad effects of water being spilt and making manure handling more difficult.

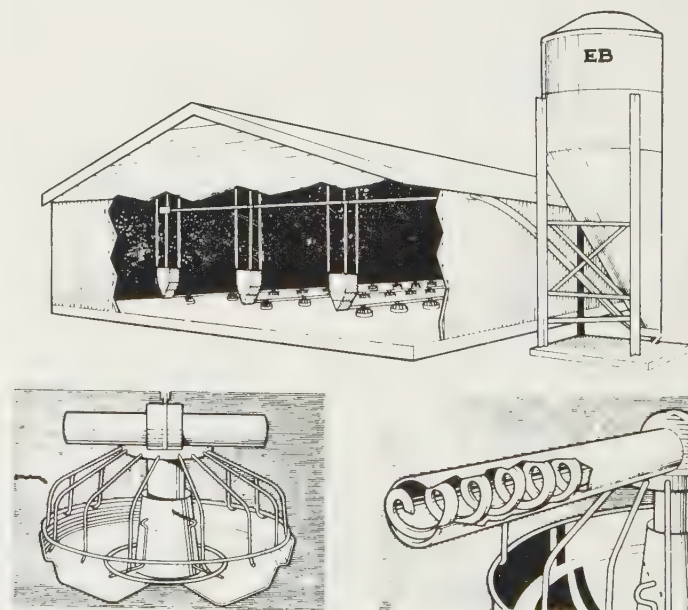


Fig. 19.16 Automatic poultry feeding system with open-centre auger conveyor delivering feed from bulk bin to lines of cylindrical dispensers. (EB)
Level of feed in each pan is adjustable. Automatic-weigh hoppers can be used to supply each line for rationed feeding. Below: left, dispenser; right, open auger conveyor.



Fig. 19.17 Line of winch-suspended automatic feeders. (EB)
Each line is supplied with automatically pre-weighed quantities at pre-set intervals.

Fig. 19.18 Automatic egg collection in a large battery laying house. (Big Dutchman)

Equipment for broiler harvesting

An early chicken catcher, the Tamdev APS2000, received awards at the European Poultry Fair at Stoneleigh in 1984 and 1985. At this time the Silsoe Research Institute had already begun research and development work on the same subject, and a published BSRAE paper by the Institute's Farm Buildings Division dated 1985 provided an introduction to the commercial and animal welfare problems on which the Institute's work was based. The conclusion reached at that time was that most injury to the birds occurred during manual catching, carrying, transfer, loading and unloading, and that there were sound grounds for continuation of development work on equipment to minimise such damage. Work at Silsoe Research Institute was concentrated on a fairly small and highly manoeuvrable self-propelled harvester with a rubber fingered pick-up head of very gentle action mounted on a





Fig. 19.19 Automatic chicken catcher.
Comprising catching unit, chassis truck and crates loading system: made by Agritec under British patent licence from British Technology Group.

sweeping arm capable of clearing a path through the birds considerably wider than the machine itself. The device for collecting and lifting the birds off the floor consists of three rotors each fitted with several rows of soft rubber fingers. As the machine sweeps to the right the central and right-hand rotors counter-rotate, and the birds are picked up gently and deposited on a sloping conveyor belt. When the machine sweeps left the centre rotor changes direction and counter-rotates with the left-hand rotor. The conveyor belt moves the birds to the rear of the machine, where they are automatically placed into containers on the rear crate-stacking unit. Field trials have shown collection rates of over 6000 birds per hour, and modular systems have been organised for handling the crates into road transport vehicles. The Silsoe Research Institute patented designs are available for licensing to equipment manufacturers and the British Agritec machine

illustrated in Fig. 19.19 is from an early production batch. A Silsoe Research Institute publication (see references list) gives further information.

Sheep-shearing machines

Sheep-shearing machines have now displaced hand shears on a great number of sheep farms all over the world. Their advantages over hand shears lie in the saving of labour and in the fact that they enable comparatively unskilled men to do the work.

The operating principle of the shearer is the same as that of the cutter-bar of a grass mower. The cutter, which corresponds to the mower knife, reciprocates between the comb and the forks of the shear head. It is driven at high speed (up to 3000 strokes per minute) by a flexible

shaft which may either be driven by electric motor or small engine. The knives move over several closely set teeth of the comb in order to produce short and even cutting. For good cutting the combs and cutters must both be kept sharp; grinding may be effected by means of a revolving disc covered with emery cloth.

Double insulation of electric machines by enclosing the drive unit in a tough moulded non-conducting shell provides improved safety. A sound, high support which leaves the flexible drive just clear of the floor is needed; lightness of the unit is an advantage. Modern needs include use for crutching and for preparing ewes for use of ultra-sonic equipment in pregnancy diagnosis. A variable-speed drive operated by a knurled ring at the top of the flexible drive connection can provide a speed reduction of up to 40% which is useful for such duties (e.g. Sheba-Keen).

Electric fences

One of the most valuable special uses of electricity is in connection with the electric fence. British electric fencer units incorporate design features covered by a British Standard Specification. Battery models employ a 6-volt accumulator to supply the energy. This provides current in a primary coil, which induces a small current of high voltage in a secondary coil. As in the magneto, a contact-breaker continually makes and breaks the primary circuit. The current flows approximately once a second, and lasts for about one-hundredth of a second. The secondary coil is connected to the insulated fence wire, and animals touching the wire feel a sharp and temporarily painful sting.

A battery of 20 ampere-hours capacity will last for 20 days of continuous use, and will electrify up to 24 km (15 miles) of fencing. One wire at 600–750 mm (24 to 30 in) is adequate for cattle and horses. Sheep and pigs need two wires at about 300 and 450 mm (12 and 18 in), and goats three at 250, 500 and 750 mm (10, 20 and 30 in). Light stakes at 6–9 m (20 to 30 ft) spacing provide adequate support for the fence wire.

Proper insulation of the wire is one of the essentials, and is secured by nailing or wiring solid porcelain or plastic insulators to the fencing post at the required height. The fence wire must be kept clear of weeds, grass and branches.

The fencer unit itself must have a good earth connection,

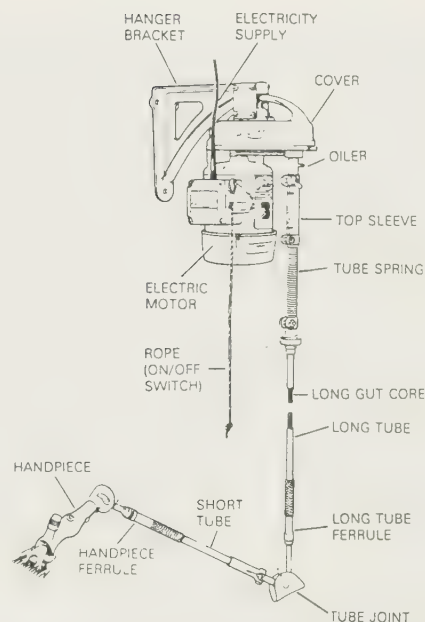


Fig. 19.20 Electric shearing set with $\frac{1}{3}$ hp fan cooled motor providing choice of three operating speeds by moving V-drive belt to appropriate pairs of pulleys located beneath top cover. 'Solid' down-tube drive is shown: flexible drive is optional. (Lister Shearing Equip't)

and this is conveniently achieved by mounting the unit on a metal post or tripod which is driven well into the ground.

Mains-operated fencer units are also available, and a British Standard covers safe methods of construction which should always be adhered to.

It is important to train stock to respect the fence, since it is not the wire itself which stops them, but only fear which keeps them away from it. To train stock, tempting food should be placed on the far side of the wire and the animals allowed to approach it slowly. They will soon learn to avoid the wire which gives them such an unpleasant sting.

Sheep's-foot trimmer

Sheep on lowland fields cannot wear down the growing horn on their feet by natural means, and trimming is essential to combat foot diseases that result in lameness.

A man using a knife or clipper can trim about 100 sheep in a day. A special-purpose machine (McConnel) can trim a flock of 500 in about $\frac{1}{2}$ hour. With the machine, treatment is ideally carried out monthly, when only about 3 mm ($\frac{1}{8}$ in) of horn needs to be removed. The trimmer consists of a pto-driven device mounted on a tractor three-point linkage, with abrasive belts running in the bottom of a V-shaped race through which the sheep walk. The belts run at high speed in the same direction as the sheep walk. An adjustable divider separates right and left legs, and each hoof is divided by a narrow ridge with a herringbone pattern that supports the weight of the sheep but allows the protruding nail to press lightly on the moving belt. A jet of water, to which a medicant can be added, is used to keep the belt free from horn and small stones.

Livestock weighing machines

There is a vast range of weighing machines for pigs and cattle, ranging from relatively simple crates suspended on a spring balance, to automatic electronic machines that provide an accurate digital display of the weight within seconds of the animal entering the machine.

Simple hydraulic weighers have at each corner hydraulic capsules connected with a vertical scale. An advantage of this type is the silence and very small platform movement.

The more complex machines employ load cells with electronic equipment to provide a dial or digital reading. The advantages of the digital type are such that the system seems likely to become widely accepted on farms where a great deal of stock weighing is necessary.

Straw choppers for livestock bedding

After trials of many other materials, chopped straw is widely accepted for cubicle bedding where baled straw is available or easily obtained. Chopping and spreading machines may be broadly divided into pedestrian-controlled engine-driven and tractor-mounted pto-driven. The latter can be used where slurry scrapers work, and have advantages in power available, less exposure of operator to dust, and less fire risk. The principle of operation first introduced on pedestrian machines and successfully employed on both is designed for conventional



Fig. 19.21 Tractor-mounted bed-straw chopper, for small bales, delivering the chopped straw to cubicles on the nearside. Each chamber is rotated in turn to the chopping blades. (Kidd)

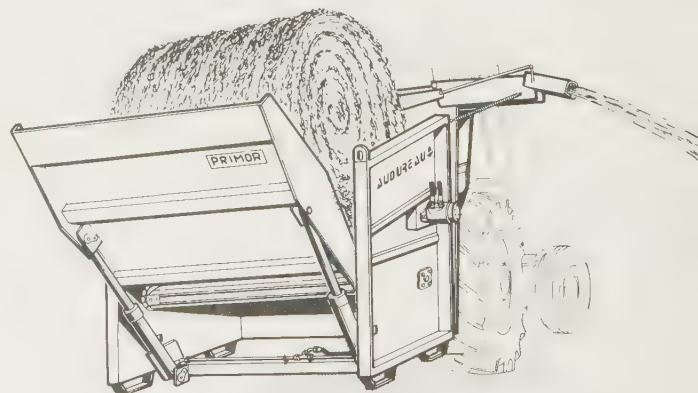


Fig. 19.22 Three-point linkage mounted baled straw chopper-distributor with hydraulically controlled rear door, hydraulic motor driven endless conveyor floor and rotary spiked drum de-compactor, which delivers the peeled-off bale layers forward to the direct pto drive, (with torque limiter) 'turbine' chopper carrying eight bolted on blades running at 1500 rpm. After strings or net are removed and the drives switched on from the cab, the delivery chute angle is adjusted as necessary using a hydraulic control. The floor conveyor is reversible if necessary. Range of straw distribution is normally up to 14–15 m. (Audureau Primor PP)



Fig. 19.23 Tractor rear mounted big-bale straw chopper with tub diameter 1.88 m (6 ft 2 in) being loaded with wrapped big bale. The tub has hydraulic drive and three possible outlets giving a choice between normal and short chop, plus an elevated 'Kobra' outlet as fitted, or flexible blower format with up to 10.7 m (35 ft) of 180 mm I.D. (7 in) plastic tube, with or without adjustable gantry facility (applies to model 6–10 only). Stabiliser wheels are fitted to top model only. (Kidd Model 6–10)

rectangular bales (e.g. Fosse, etc.). An open-top rectangular hopper receives a single bale on end, and rotates it slowly about a vertical axis. Adjustable-height fingers support the bale just above the power-driven horizontal rotor which has four rows of knives to chop and distribute the straw, usually to one side only, with the help of adjustable flaps. On tractor machines it can be an advantage to carry an extra 1–4 bales. Average chop length is 25–100 mm, and experience shows that such material

spreads evenly in cubicles, is much more efficient than long straw at keeping stock clean, and seldom causes problems in slurry handling.

Among many other types, some suitable for handling big bales in yards, is one in which the hopper comprises four single small rectangular bale chambers arranged to move in succession, by quarter-turn rotation, to the position where chopping takes place. Chopping is by knives on the upper face and periphery of a bevel-gear-driven, horizontally rotating flywheel. Inclined blades partially chop and move the straw to the flywheel periphery, where the main ring of 12 triangular, vertically attached, 75 mm, replaceable knives works in conjunction with a concentric ring of 16 similar fixed knives. The chopped material is directed to either or both sides by rope-and-spring controlled flaps (e.g. Kidd, Fig. 19.21).

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Equipment for Milk Production

Machine milking is the normal method for British dairy herds, both large and small. Many farmers who have been machine milking for several years have changed to new equipment and new systems in order to eliminate unnecessary work. The use of milking parlours is steadily increasing, and important developments include equipment specially designed to facilitate easy cleaning by chemicals and to remove the teat-cups as soon as milking is finished. Milk is handled in bulk at all stages and this automatically ensures effective refrigerated cooling in the bulk tank. Feed dispensers for milking parlours are dealt with in Chapter 19. British manufacturers have developed a vast range of equipment for all these purposes, and only a brief outline can be given in this chapter of the main features of the most common types.

Essentials of a milking machine

An electric motor or small engine drives a vacuum pump, producing a suction which is transmitted by a pipeline to the milking units. This suction is continuous, but the teat-cups are double-walled, with metal bodies and rubber linings; a device called the pulsator alternately connects the space between the metal walls and rubber linings, first with the atmosphere and then with the suction. When the space between the 'liners' and the metal walls is connected to atmospheric pressure, the liner collapses, squeezing the teat, and the vacuum level inside the liner is momentarily reduced. This intermittent squeeze and release is essential to machine milking. The massaging action of the liner on the teats aids circulation of the blood in the teat, avoiding constriction by the application of continuous vacuum. This massaging action also has some effect on stimulating 'let down' of the milk from the alveoli, where it is secreted, through the ducts to the teat cistern.

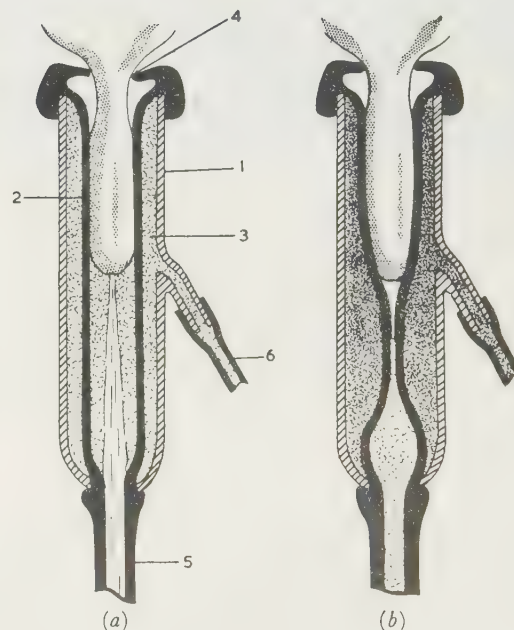


Fig. 20.1 Principle of teat-cup action. (drawing NIRD)
 (a) 'Release' phase during which most milk withdrawal takes place.
 (b) 'Squeeze' phase.
 1 Metal shell, 2 Rubber liner, 3 Annular chamber, 4 Liner mouth, 5 Rubber milk tube, 6 Rubber pulse tube.

The vacuum pump may be of rotary or reciprocating type. It sucks air from the vacuum reservoir and pushes it out to atmosphere. In general, rotary pumps work more smoothly and have fewer moving parts. A typical rotary pump has sliding vanes that are kept against the walls of the pump chamber simply by centrifugal force. Such a pump needs a good mist-lubrication system to provide the correct dosage of oil during operation. One widely used type provides, in addition, a special dose of oil at

each start (Fig. 20.2). The pump usually maintains a vacuum of 380 mm (15 in) of mercury, or about 0.48 bar (i.e. about one-half of the normal atmospheric pressure). A vacuum controller is placed in the pipeline, in order to ensure against an excessive vacuum, which might be harmful to the cows. In addition, a vacuum gauge and moisture traps should always be incorporated in the pipeline. A lower vacuum (0.4 bar) is employed by one manufacturer (Westfalia) in a plant with a large-bore (70 mm diameter) low-level milk pipeline, with a vacuum pump and controller adequately sized to ensure that the vacuum level is maintained during operation. Other installations with large-bore pipeline and high vacuum reserve (e.g. Gascoigne 'ISO-Max') are operated by some users at about 0.45 bar.

The pulsator is an air valve so constructed that suction and release impulses alternate in the air line leading to the space surrounding the rubber teat-cup liners. Pulsators may be driven mechanically or electrically, but are generally driven by the vacuum itself operating alternately on two diaphragms or on to the two ends of a piston. It is, in effect, a two-way tap. In most machines it is set to give from 45 to 65 pulsations per minute.

Research at the NIRD has confirmed that there is considerable advantage as regards speed of milking in using a pulsator that provides for a long release-period

and a short squeeze period. As a general recommendation, the vacuum level should be 15–18 in of mercury (0.48–0.58 bar), the number of pulsations per minute should be about 60, and a release : squeeze ratio of about 1.5 to 3 : 1 should be used. This results in rapid milking without harmful effects. In practice the cycle does not consist simply of suction and squeeze but includes also a lengthy period of increasing vacuum and a usually shorter one of falling vacuum. A requirement of ISO performance standards is that the period at nominal working vacuum shall be not less than 30% of the total cycle, and that at atmospheric pressure not less than 15% (see Reference list). One method of ensuring a uniform pulse is to employ an electrically operated master pulse controller, which transmits an electrical pulse through an electrical conductor to an electro-magnetic air valve located in each milking unit. There is then the usual pneumatic transmission of the pulse to the teat-cups. This device ensures uniformity from unit to unit and from day to day, and at the same time enables the operator to vary, within limits, the proportion of time accounted for by squeeze and release respectively.

Some manufacturers arrange for squeeze and release to occur simultaneously on all four teats, while others arrange to alternate action on left- and right-hand pairs. There is no positive information to prove that one system is better than the other.

The teat-cups are an important feature of a milking machine. The type now generally accepted has cylindrical metal cups with rubber liners, but there are variations in details of design. One essential is that the cups should be easy to clean and assemble.

New types of synthetic rubber liner have properties of flexibility and softness that remain virtually unchanged over a wide range of temperature, and also have advantages compared with natural rubber in reduced fat absorption and a long useful life.

The Ambic 'Hydraflow' milking system, based on principles developed at the former National Institute for Research in Dairying, provides a higher average milking vacuum at the teat end than is achieved with conventional milking equipment. The cluster units are light, compact, easy to handle, and were found less prone to liner slip and cluster fall-off than some conventional units by the RASE Machinery Award judges during visits to commercial users before the Society's Silver Medal Award was made to the Company in 1989. The users reported

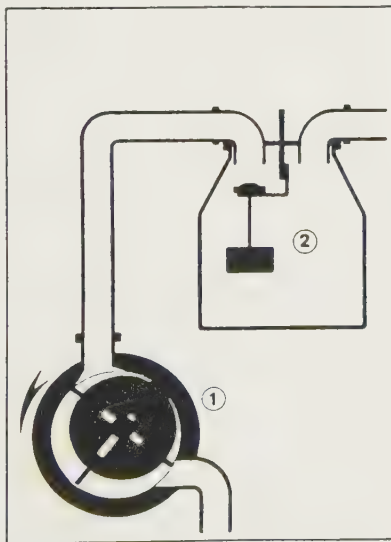


Fig. 20.2 Action of (1) rotary vacuum pump and (2) sanitary trap. (Alfa-Laval)

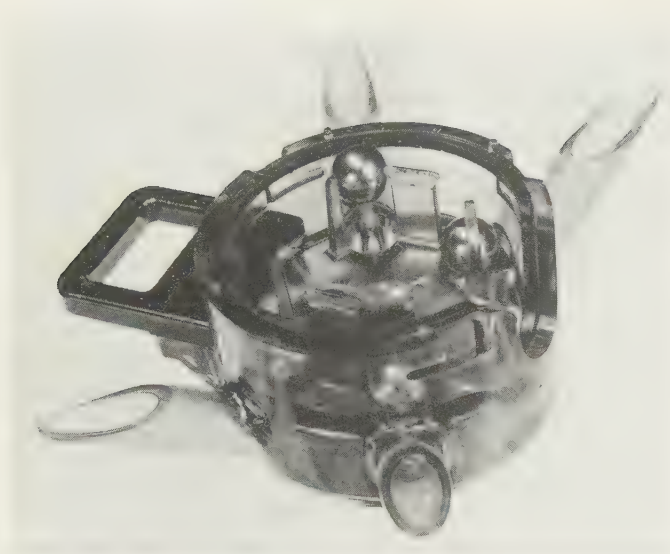


Fig. 20.3 Light plastic claw base section of Ambic Hydraflow teat-cup unit showing arrangement of ball valves which play a significant part in improved milking performances reported by users. (Ambic Equipment Ltd)

quicker milking, better mastitis control, improved milk quality, and easier herd management as result of the sum effect of such factors. Costs of change-over to the system were found very economic (see Fig. 20.3).

Types of milking plant

In Britain, practically all new milking machinery is of the parlour type, and the transition to use of refrigerated bulk tanks and bulk collection has been rapidly achieved with the help of financial incentives. Bucket and direct-to-churn plants, however, remain of interest in less developed countries.

General design of installations

One of the most important requirements of a milking machine installation is that the vacuum level should remain constant throughout a normal milking routine. This ideal cannot often be achieved, but any variations that do occur should be small and the recommended vacuum level should be regained within about five seconds. If this

is to be achieved, the vacuum pump must have an air extraction capacity greater than that required just to maintain the recommended vacuum level when all milking units are operating and, in addition, the vacuum controller must operate efficiently. As this reserve of pump capacity is required mainly to deal with the extra air let in when units are changed, the amount of reserve capacity required will depend largely on the number of units. Specifications of construction and minimum performance requirements for milking installations are given in BS 5545, which is based on ISO 5707. Recommended vacuum reserve for plants with up to 10 units is:

Effective reserve =

$100 + 25n$ l/min free air for pipeline plants

and

$40 + 25n$ l/min free air for bucket and direct-to-can plants

where n = number of milking units. Separate recommendations are made for larger installations.

Minimum capacity of the vacuum pump specified by the ISO proposal is: $150 + 60n$ l/min free air for installations of up to 10 units, with modified provisions for larger plants. Air consumption requirements of ancillary equipment and operations such as in-place cleaning and automatic cluster removal must be allowed for. Provision of a separate vacuum system can be the best way of operating ancillaries.

The bore of the piping used for the vacuum system is also important in maintaining a constant vacuum level throughout the plant. In parlour or round the cowshed milking plants it is essential that the pump, sanitary trap, vacuum controller and milk receiving vessel should be as close together as possible. In most modern milking installations the air-flow is split between two or more pipes and except in very large plants 25 mm (1 in) bore piping will be suitable to carry part of the total air-flow. The only part of the vacuum system which carries the total air extraction capacity of the pump is the pipe that leads from the vacuum controller through the sanitary trap to the vacuum pump. Recommended diameters are 25 mm (1 in) for flows of less than 300 l/min, 32 mm for 300–599 l/min, 38 mm for 600–1000 l/min and 50 mm for over 1000 l/min.

In a new installation the difference in vacuum level between the pump and the extremities of the plant should be hardly detectable and certainly should never exceed 25 mm (1 in) Hg. In old installations vacuum differences are often due to restrictions in the pipeline system caused by dirt and deposits.

The releaser mechanism transfers the milk from the milk receiver vessel (usually situated in the dairy), where it is under vacuum, to the bulk tank or churn. This is usually done by an electrically driven rotary pump which is switched on or off according to the level of milk in the milk receiver vessel. Vacuum operated diaphragm pumps which run continuously are still used, especially where the electricity supply is unreliable.

Pipeline installations

Great improvements in equipment and cleaning methods have made it practicable to introduce pipeline milking into long cowsheds. This is not necessarily desirable if loose housing and parlour milking are practicable; now that the use of cubicles has been fully proved, there are few circumstances where a forward-looking farmer will not need to consider this possibility. The use of a pipeline in these installations, which has the dual function of providing the milking vacuum and conveying milk, makes the maintenance of a steady milking vacuum at the teat-cup very difficult. The way in which the pipeline is installed is important. It should have a steady fall of about 1 in 84 from all milking points to the milk receiver vessel. BS 5545 recommends caution in choosing pipe sizes; long lengths should be avoided: length, milk flow and air flow are all involved. Diameters formerly considered suitable often need to be increased.

Milking direct into a pipeline makes the recording of milk yields more difficult. Milk meters help to solve this problem, but they can be rather clumsy to carry from cow to cow.

Milking parlours

Systems of milking used in modern milking parlours include:

(1) Milking direct into an overhead pipeline which con-

veys the milk to the milk receiver vessel as in cowshed pipeline milking.

- (2) Milking into a graduated glass jar where the individual cow yields can be measured. The milk is transferred by vacuum in a pipeline to the dairy.
- (3) Use of wide-bore pipelines at a level lower than the cows. Milking into these low-level pipelines is more efficient than using overhead pipelines.
- (4) A modification of (1) with a wide-bore (76 mm) overhead line direct to milk pump receiver assembly, with automatic equipment to provide air-blast injection during circulation washing at regular short intervals during the cleaning operation.

Types of parlour

Modern milking parlours are designed to ease the job of milking. When two-level parlours were first used in Britain, small tandem and 'chute' types in which the cows stand head-to-tail were among those installed. These are no longer considered for new installations, and are now rarely used. Some *abreast* parlours in which the cow standings may be up to 460 mm (18 in) above the operator's floor level remain in use, but are rarely considered for new installations. Current questions are concerned mainly with which particular type of herringbone, and with all of the many important details involved.

A typical *herringbone* consists of two parallel lines of cows, with the pit about 0.75 m (30 in) below the cow standings in between.

The 'Polygon' and 'Trigon' are variations of the herringbone in which the lines of cows are broken, and not parallel. Reasons for choosing one of these in preference to a large herringbone may be summarised as:

- Reduced operator interruption time at cow entry and exit.
- Wide milking pit improves working conditions, visibility and quick attention to malfunctioning.
- Slow-milking cows hold up only a quarter or third of those in the parlour.
- Polygons aim to provide efficient working conditions for two men at herd sizes above about 250, and
- Trigons for one man handling 100–300 cows.

Two arrangements of milking units are possible in simple herringbone parlours. A milking unit can be shared between two stalls or each stall can have its own unit. In

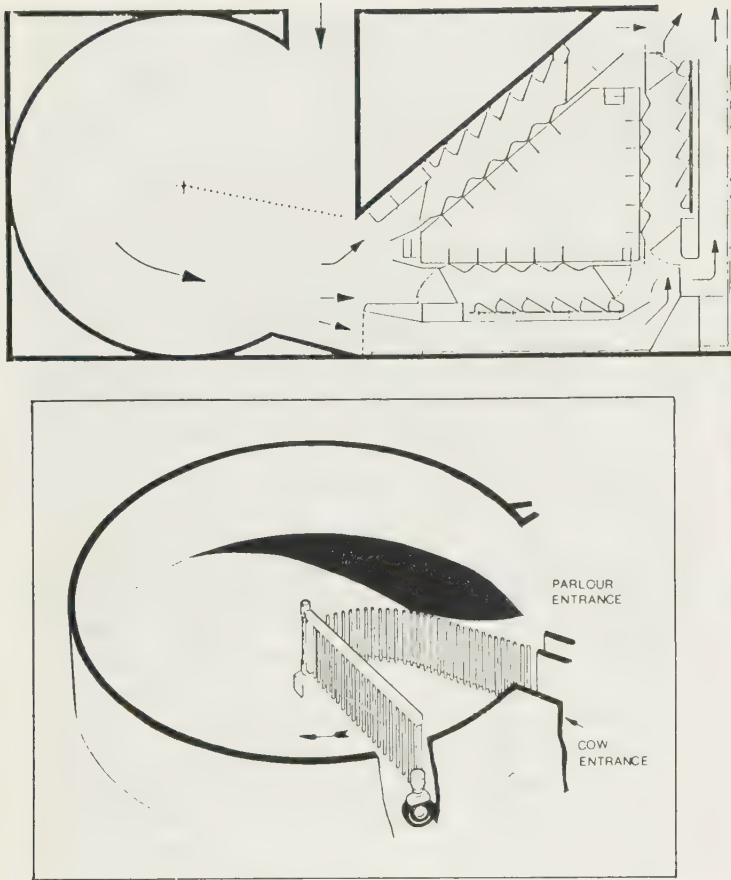


Fig. 20.4 Plan of three-sided ('Trigon') 16-stall (6-6-4) milking parlour with comb-gate entry. Arrows show cow flow. Manger gates, and entry and exit gates operated by compressed air speed up cow entry and exit. The comb-gate (shown below for clockwise use in another two-entry parlour) passes through the line of fixed posts and with its horizontal rail above their tops. It is supported by a pneumatically-typed wheel driven by a 1 hp motor through reduction gear and safety slipping clutch. (Gascoigne)

the two-stalls-per-unit parlour the cow is prepared for milking in one stall while the unit milks the cow in the other. This arrangement gives the cows more time to eat concentrates and the milking unit is idle for only a short time between cows. With the one-stall-per-unit parlour the milking unit must stand idle while the cow is prepared for milking and the cow has only a short time to eat

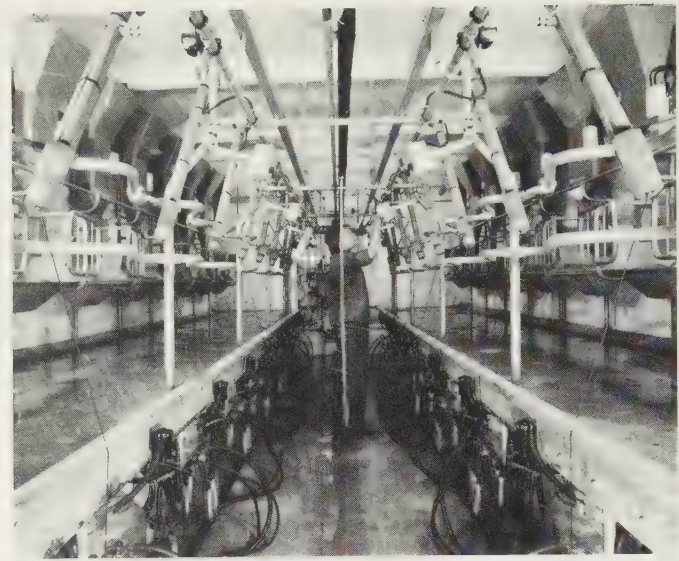


Fig. 20.5 Automated parlour with low-level recorder jars, vacuum-operated auger feeders, vacuum-operated cantilever gates and manger-guards, and electro-pneumatic automatic cluster removal. (Alfa-Laval)

concentrates. There are several ways of overcoming this problem, such as:

- Feeding a basic part of the concentrate ration outside the parlour, in stalls where the cattle are temporarily yoked.
- Feeding concentrate well mixed with the bulk ration in a 'complete diet' feed system.
- Use of 'out-of-parlour' concentrate dispensers.

By use of programmable out-of-parlour feeders in conjunction with advanced types of herringbone parlours, high-yielding cows can be given intended individual treatment even in very large herds. (See also Chapter 19.)

Other factors involved in choice of herringbone type may include consideration of location of recorder jars, and milking direct to a large-bore milk pipeline. Method of recording yield and checking disorders is involved. Possible methods include the use of low-level weigh jars or milk meters with automatic recording (Figs 20.6 and 20.10).

Major improvements in milking installations on large-scale and progressive dairy farms now inevitably involve

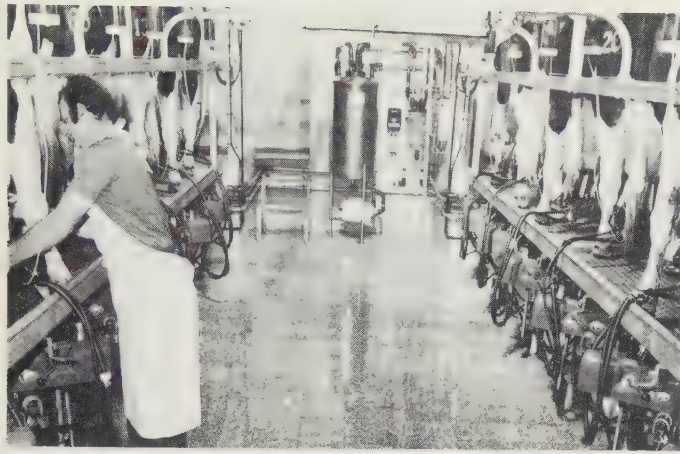


Fig. 20.6 Uncluttered herringbone parlour with low-level weigh jars in a protected position beneath the chequer-plate platform. Milk weight can be automatically recorded. (*Fullwood*)

improved electronic equipment involved in individually rationed feeding of concentrates, faultless milk recording and sampling, and the ease with which essential management information can be put on record in the farm office and regularly up-dated.

Figure 20.7 illustrates some of the milking parlour items in an up-dated Gascoigne/Melotte installation. One of the essential features is the line of MR 2000 milk meters neatly housed beneath the deck and illustrated individually in Fig. 20.8. The body of the unique meter consists of three chambers which communicate via a double-acting valve. The milk passes gently by automatic electronic controls from the entry chamber to the measuring chamber and finally to the outlet in units equal to 500 grams of milk, each of which is automatically recorded. At the end of each milking the remaining milk is metered to the nearest 100 grams and the total displayed as large bright digital readouts on the control box overhead.

Features cover high measuring accuracy, stable milking vacuum, high flow rates, precise milk sampling, thorough automatic washing, and acceptance by international authorities that the equipment complies with agreed standards. Automatic cluster removal is normally fully integrated, and automatic reset can be operated by parlour gate switches. Links to memory feeder and yield recording are

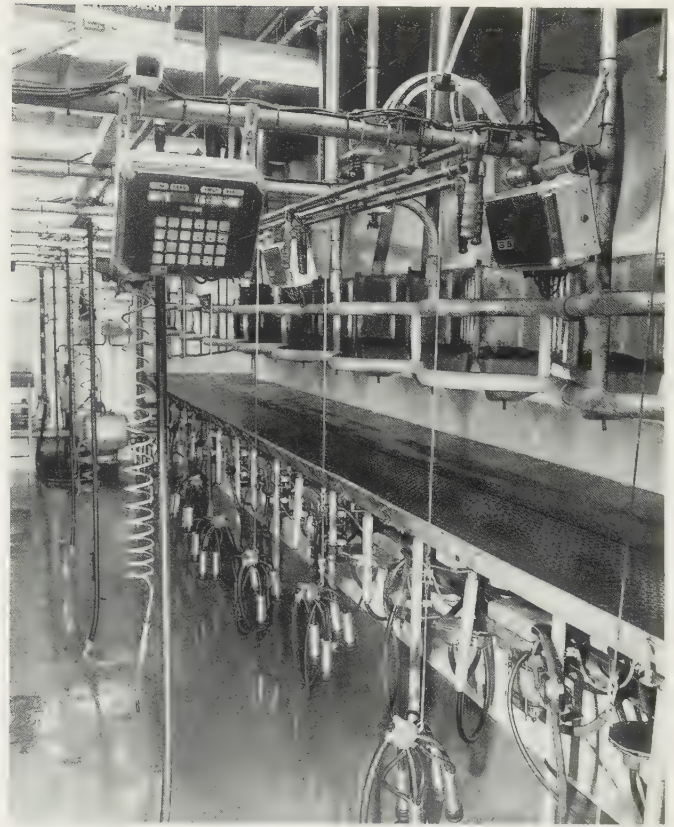


Fig. 20.7 Fully automated herring bone type milking parlour with integrated MR 2000 milk meters, MR 2000 Memory Feeders, computerised recording system and automatic cluster removal. (*Gascoigne Melotte*).

a normal need, and those to an integrated total farm management system available where needed.

Automatic cluster-removal

Most automatic cluster-removal devices without electronic meters are based on passing the milk through a small chamber in which the size of outlet is regulated by a float. During most of the milking period the outlet from the chamber is large because a full flow of milk causes the float to rise. As the flow decreases a point is reached where the aperture is almost closed, and at this point the float triggers off a mechanism which, after a suitable

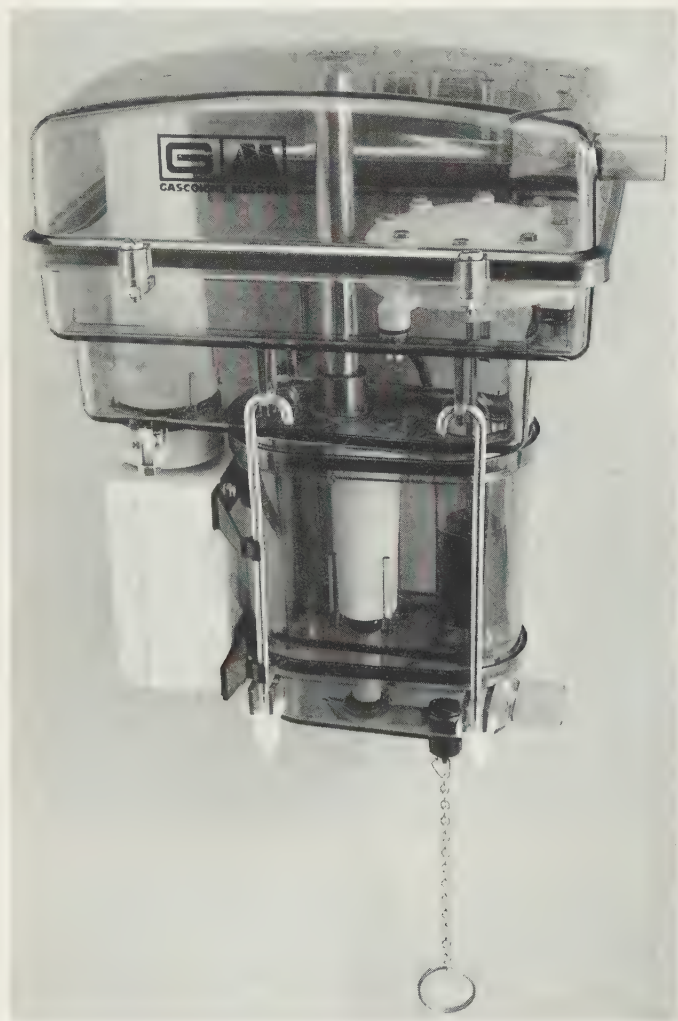


Fig. 20.8 MR 2000 Milk Meter with precise milk sampling, high measuring accuracy, thorough automatic wash, and control box with clear digital read-out. At beginning of milking, communication between entry and measuring chambers is blocked by valve until milk flowing in covers electrical probes: then valve is opened and milk flows to measuring chamber which holds 500 grams and automatically records each transfer of this quantity. When milk flow ceases and electrical probes at entry are uncovered, milk remaining in meter is automatically recorded and total displayed. Precise milk sampling device is built into meter. (Gascoigne Melotte)

delay, release the vacuum at the teat-cups and causes an air-operated piston to pull off the cluster by means of a cord.

Electronically controlled ACR

The whole procedure can be automated (Fig. 20.9) after a 'start' button is pressed. This operates a solenoid valve to allow air into the cylinder, permitting the cord to be pulled down and the teat-cups put on. A timer delays premature take-off by 2 min, by which time milk flow should have reached the minimum rate (0.2 l/min) at which milking can proceed normally. When the float in the flow indicator falls, flow having fallen to this critical figure, a reed switch starts the electronic timer, which delays take-off for an adjustable time up to 60 s. After this, the solenoid valve is automatically moved to apply vacuum to the cylinder, and the cord is pulled upwards. The first pull on the cord opens an air valve in the upper part of the claw, to reduce vacuum level at the teats before take-off, and to shut the outlet valve in the cluster afterwards.

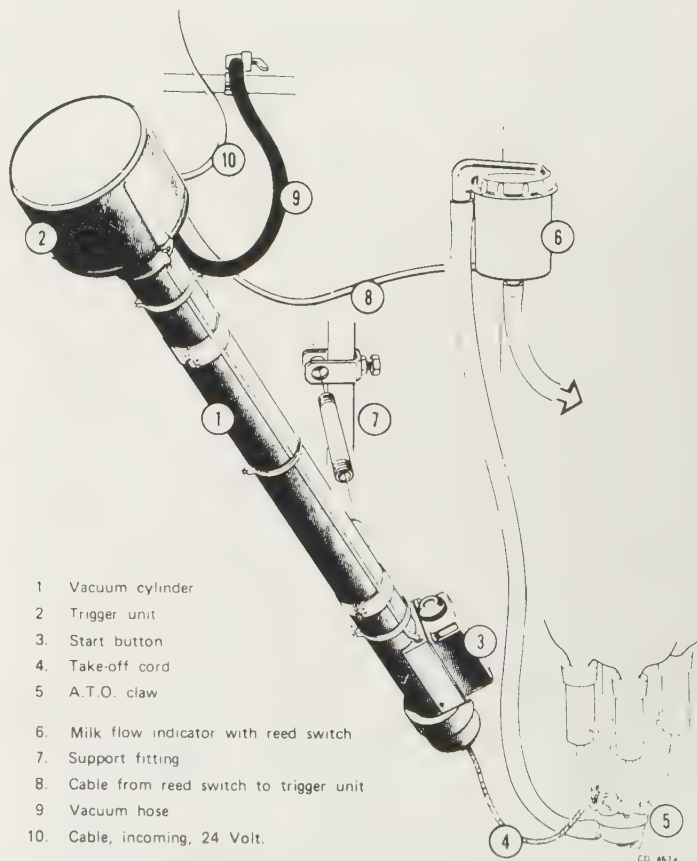


Fig. 20.9 Automatic cluster removal unit. (Alfa-Laval)

Automatic milk recording

With the rapid development of the use of electronics in milking parlours, automatic recording becomes fairly easy. Recorder jars have advantages: they are a useful aid to vacuum stability, permit easy inspection of individual performance and make isolation of unmarketable milk easy. They also permit use of a simple means of automatic recording by strain gauge and microprocessor. On large installations low-level large-bore pipe-lines with suitable milk meters offer similar advantages without the necessity of using jars.

Dairy automation and herd management

Potential benefits of dairy automation include considerable saving of labour needed for milking, feeding and yield recording; easier and more efficient record-keeping, and more economic production arising from improved decision-making and control of management. Many of the benefits can be obtained cheaply, without automatic

identification (e.g. Dataface 'Dairylog'). Even where a system providing automatic identification is an ultimate aim, it can be advisable to proceed in stages extending over a period of years, beginning with appropriate modules from a comprehensive system (e.g. Fullwood, Hunday, etc.). With pedigree herds of high value, full automation can be justified for about 100 cows upwards; and it can facilitate one-man milking of commercial herds of up to about 300.

Typical equipment and techniques involved in full automation include an individual transponder for each cow, usually located in a neck-band; it identifies the animal to the computer at mangers in the parlour and/or in out-of-parlour feeders. At the office end of the system is a micro-computer with a dairy management programme, and a data printer. The computer has a visual display facility and can be of a type capable of increased future use. A separate automatic yield recorder may be used to store the yields of a milking or a day until the batch is transferred to the computer by positive operator action.

The computer stores the essential data about each cow's history and current needs; it is linked to out-of-parlour feeders by a controller nearby. This, and a similar feed control link in the parlour, are provided with a facility for manual over-ride. The parlour link needs a means of transmitting messages on health, etc., for recording and action.

Milk meters or strain-gauge weighers measure and transmit yields. This provision is normally linked to the automatic cluster removal equipment.

A good dairy management programme provides for rapid decisions on feed changes by dividing the cows into groups, and making available not only group yields with percentage increase or decrease, but also margin over concentrates at chosen intervals, and provision for immediate change of ration applying to all of the cows in the particular group.

Recorded notes of insemination, pregnancy diagnosis and common ailments of individual animals can provide a sound basis of communication between operator and manager on larger farms. The information held by the computer concerning both individual animals and groups is immediately available as a visual display; and a printed record of individual and group performances on a weekly basis provides a convenient management tool. The use of such equipment on progressive farms with a dairy herd is certain to increase.

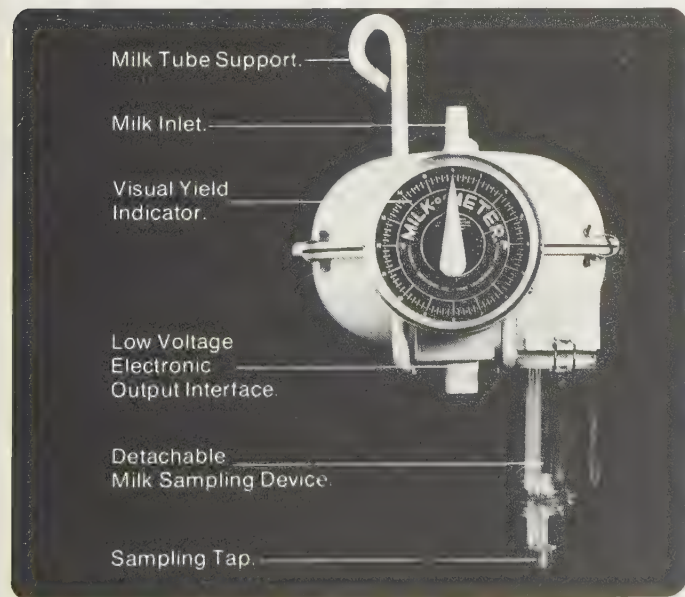
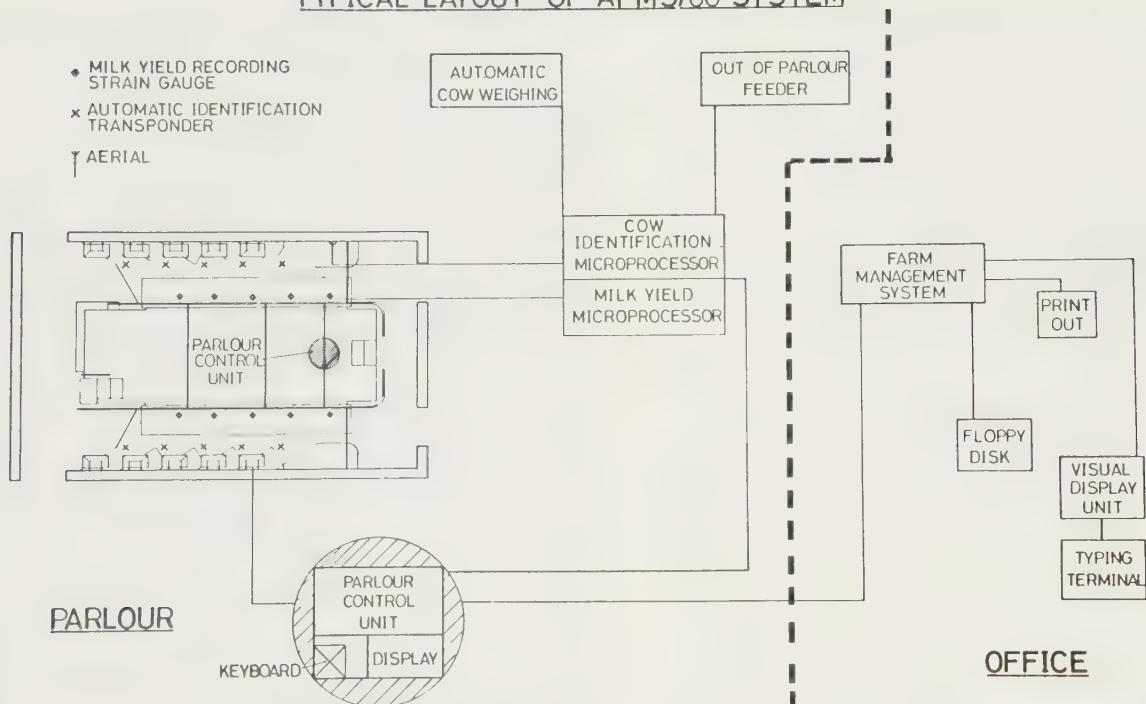


Fig. 20.10 Milk meter, with visual yield indicator, designed to provide fully automatic milk recording for direct to line milking installations. The electronic output interface transmits individual cows' daily yields to a print-out facility in the farm office. (Hunday Electronics)

TYPICAL LAYOUT OF AFMS/80 SYSTEM



Above: Layout of AFMS/80 Modular Herd Management System with automatic cow identification. (Fullwood)

Below: Typical main equipment items in fully automated Dairy Herd Management System. (Hunday)

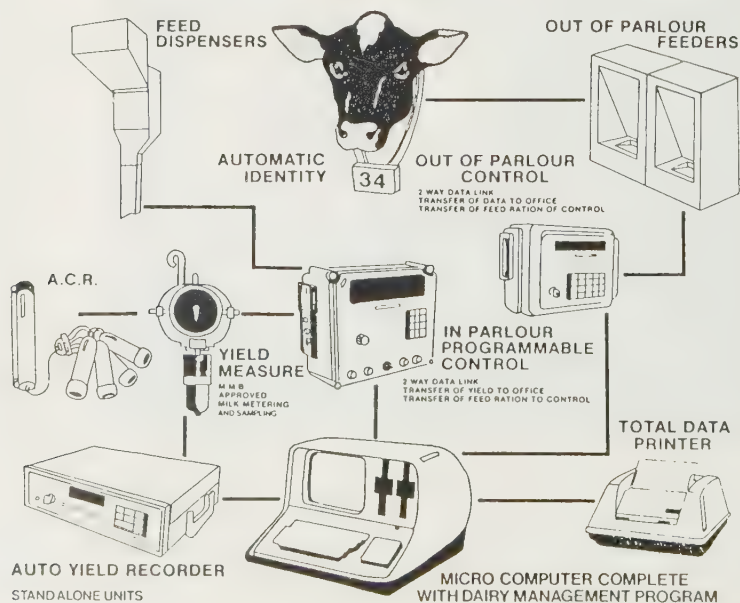


Fig. 20.11 Typical layout and equipment for automated dairy herd management systems.

Cleaning and sterilising dairy equipment

In the past the most popular method of sterilising milk equipment was by steam. This has now been almost entirely superseded by chemicals. More recently, however, there has been a return to the use of heat for sterilising, but in this method hot water is used instead of steam.

The chemicals most commonly used for sterilising are hypochlorites, iodophors and, to a lesser extent, caustic soda solutions.

Hand washing

Only bucket milking-machines and equipment such as milk coolers are now washed by hand. The normal method is to rinse the equipment in cold water and follow this with a thorough scrub in a hot solution containing an approved chemical disinfectant and a suitable detergent. A final rinse with cold water containing a small quantity of an approved disinfectant is usually given.

Circulation cleaning

This is the standard method of cleaning the parlour and around the cowshed plants. The milk is removed by a cold water rinse. A hot detergent solution containing an approved disinfectant such as hypochlorite is then circulated round the plant. Temperatures recommended vary from 60–80°C (140–180°F). After about 15 min the solution is run to waste and the plant is given a final rinse to remove traces of detergent.

A method of in-place cleaning developed at Silsoe Research Institute is known as the Acidified Boiling Water method. Water is heated to a temperature of 96°C (205°F), drawn through the plant and run to waste. No pre-rinsing is necessary to remove milk. The rate of flow through the plant is restricted so that for the 6 min during which the process lasts 13.5 l (3 gal) per unit is required. For the first two min of the process an acid solution is bled into the system to prevent scale formation. The plant is held at a temperature of between 77–82°C (170–180°F) for at least two min.

On modern plants, where the milk is delivered from the pipe-line to the cooler by a separate hydraulic pump, this also circulates water and chemical solutions for cleaning and sterilising the equipment. When the whole of the equipment is designed for circulation cleaning, this job

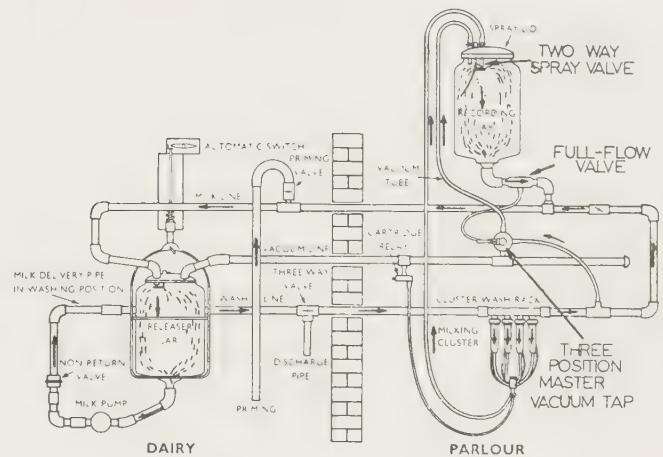


Fig. 20.12 Diagram of in-place circulation cleaning system, showing general layout of milk line, vacuum line and wash line.

becomes one that requires very little time. After the equipment has been rinsed, and a hot detergent solution circulated, a chemical sterilising solution, e.g. hypochlorite, is circulated for a time; the pump may later be stopped by a time switch and the hypochlorite left in the pipe until just before the next milking. Glass pipes make it possible to see something of the condition of the inside of the pipeline.

Air injection washing

If a large-bore high-level milk line is the chosen system, or considered as a way of up-dating an existing herringbone parlour, it is possible to supplement conventional circulation washing by an air blast injection system which forms slugs of water to scour the inner milk line faces. In one design (e.g. Gascoigne 'Isomax Highline') the air blast is automatically injected through a solenoid valve for 1.5 seconds of every 20-second cycle during the wash period. Such a system needs less washing solution and so can reduce chemical and heating costs. With the fairly low wash volume, recommended temperature maintenance is important (see Fig. 20.14).

Milk cooling

Refrigerated cooling

In hot weather, cooling by water alone may be unsatis-

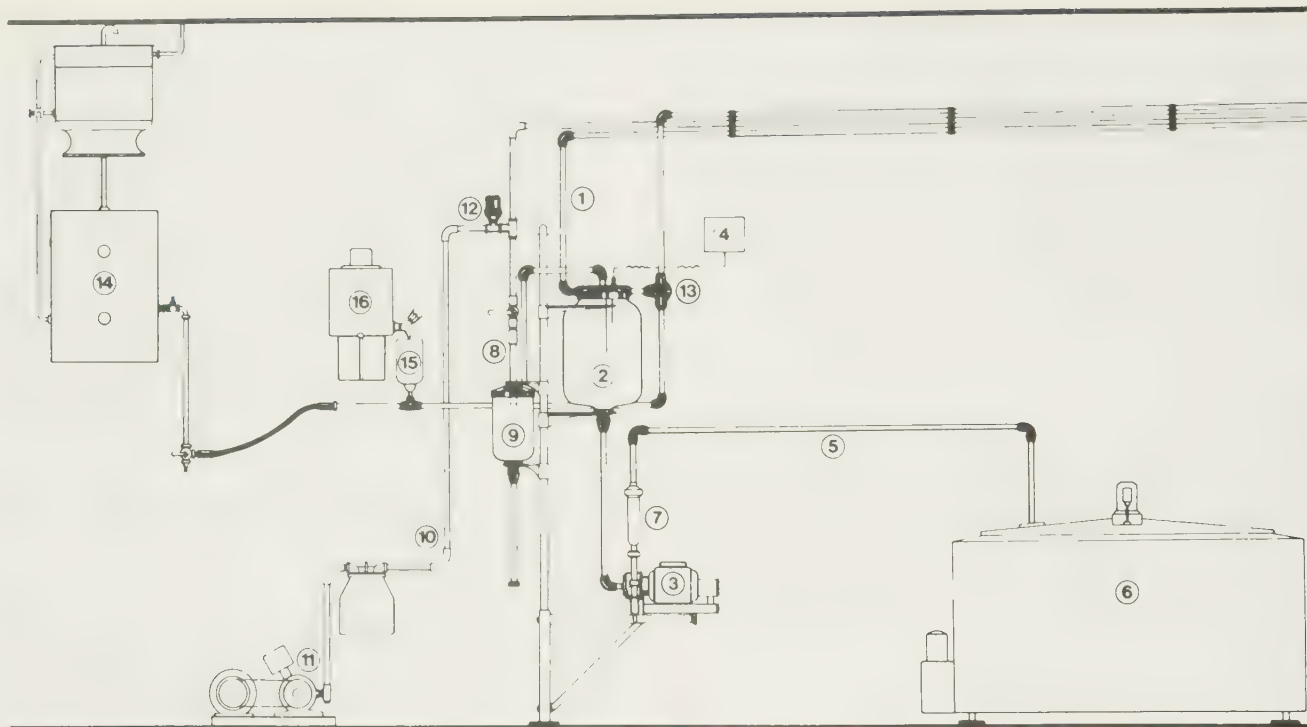


Fig. 20.13 ParLOUR milking and dairy installation. (Alfa-Laval)
Milk is transferred to the dairy via the stainless steel milk transfer line (1) to the interceptor vessel (2), from which it is removed by the stainless steel milk pump (3), the pump being actuated by the electrical probe control operating a switch in the liquid level control (4).

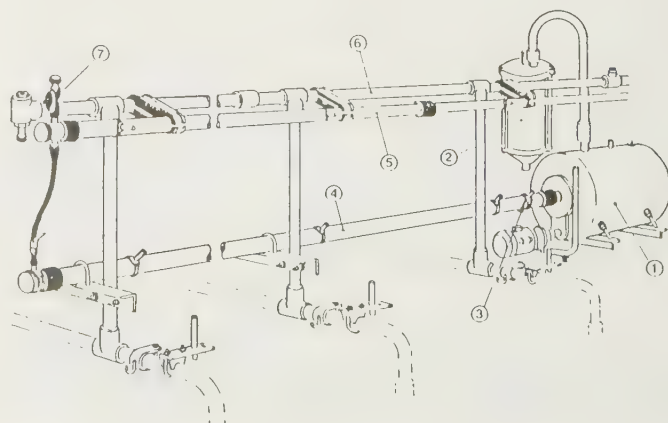
The milk is then pumped via the milk line (5) to the refrigerated farm tank (6) through a stainless strainer (7). The vacuum (8) is fed to the interceptor vessel and milk transfer lines through the water trap (9).

The galvanised vacuum line (10) from the vacuum pump (11) to parLOUR feeds vacuum to the pulsators only and serves as a support line for the milk and circulation lines. The vacuum controller (12) holds vacuum in the installation within 3% of the pre-set value.

When washing commences, the three-way rubber valve (13) is turned to connect the installation to the wash line which is connected to the water heater (14). To this line is also connected the 2 pint funnel (15) which delivers a predetermined amount of Acidal into the circulation line from the PVC Acidal storage container (16).

Fig. 20.14 General layout of large bore (76 mm) high-line milking installation with solenoid-operated air injection used during the washing cycle. Normal time cycle is 1.5 s air injection; 18.5 s rest. The injection control is operated by 12 V DC power.

1 Receiver assembly, 2 Sanitary trap, 4 Milk line with entry nozzles, 3/5 Wash line, 6 Vac/pulse line, 7 Air injector assembly. (Gascoigne 'ISO-Max Highline')



factory, especially if the supply of water is limited. On most farms it is necessary to employ a refrigerator. The principle on which refrigerators work is, briefly, as follows: an engine or motor drives a compressor which compresses a refrigerant, such as methyl chloride, ammonia or freon. Heat is developed in the compression of the refrigerant, and this is dissipated by cooling with water which may have a temperature of up to 20°C (70°F) or by air. In another part of the system the compressed refrigerant is allowed to expand, and in doing so it absorbs heat.

With *chilled water* surface coolers, the expansion coils of the refrigerating unit are immersed in water in an insulated tank: in the period between milkings, a fairly large volume of water below 4°C (40°F) is built up. Frequently, the aim is to build up a block of ice round the coils. The chilled water is pumped through the cooler and usually returned to the tank.

The advantage of building up an ice block is that the melting of a small volume of ice will absorb a large amount of heat. A small disadvantage is that care must be exercised to ensure that the size of the ice block is kept within the correct limits. Refrigerated bulk tanks are now widely used even on small farms.

Bulk milk tanks

Requirements of a good bulk tank include ease of cleaning, an effective and trouble-free refrigeration unit and good insulation. The milk must be rapidly cooled to 4°C (40°F), and maintained at this temperature until collection. The

tank must, of course, be installed where it is easily accessible to the road tanker, and it must conform to standards so that tanker drivers can empty it easily. The road tanker carries its own pump and the necessary sampling equipment. It is an advantage if the tanker driver can switch on automatic cleaning arrangements. In a typical automatic cleaning cycle, the tank is sprayed internally for two min with cold water. Iodophor (coloured) detergent solution is then applied for $\frac{1}{2}$ min, and left in contact for about 15–20 min after which there is a thorough cold rinse to remove the iodophor. (Iodophor – composed of iodine and phosphoric acid, must be an approved brand.)

Good performance of any automatic washer depends on correct installation and use of suitable pressure and jets that reach all parts of lids as well as walls and floor. Even with an efficient automatic installation the insurance of hand-washing once a month is recommended.

Most bulk tanks operate on an indirect cooling system that employs a low-powered compressor/condenser unit to produce an ice-bank. The chilled water that is circulated over the ice-bank is usually sprayed over the walls of the milk tank, the whole being enclosed in an insulated shell. In the smaller and simpler types the tank may be immersed in the chilled water, which is sometimes agitated by compressed air. In some very small bulk tanks it is practicable to use a direct-expansion system. This requires a larger unit that runs only for about four hours daily.

Bulk tanks for use in Britain must be of a type approved by the Milk Marketing Board.

Plate coolers

For very large herds the most efficient cooling system is one in which the bulk of the cooling is done by chilled water before the milk enters the storage tank. A plate cooler, consisting of a number of spaced corrugated stainless steel plates, has milk on one side of each plate and cooling water on the other side. Ordinary mains water can often be used in the first stage and chilled water in the second. The warmed mains water may then be re-used with advantage for drinking and cleaning purposes.

Hot water for milking and cleaning

For udder washing the normal requirement is about 4.5 l (1 gal) at 43°C (110°F) for each five cows where a bucket

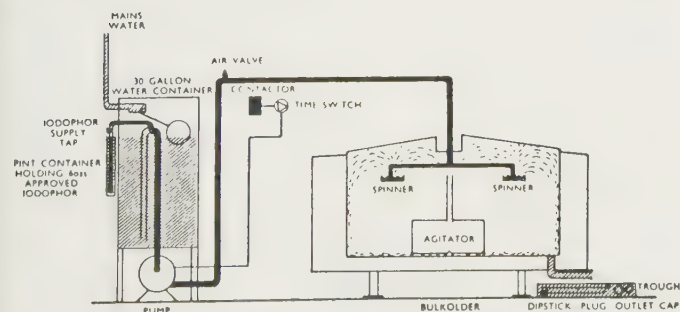


Fig. 20.15 Diagrammatic layout of semi-automatic bulk milk tank washing. (Gascoigne)
Tanker driver switches on pump and turns on iodophor supply. Cowman starts rinse and later replaces outlet cap, etc., and refills iodophor container.

and udder cloth are used. Where a spray wash and paper towels are used, the requirement is 4.5 l (1 gal) at 43°C (110°F) for each three cows. In a one-man parlour one thermostatically controlled 3 kW heater of about 10 l (2½ gal) capacity is just adequate.

For circulation cleaning, water is required at about 82°C (180°F); about 90 l (20 gal) is needed for four units and 135 l (30 gal) for eight units.

Where acidified boiling water is used, water temperature should be 96°C (205°F) and the quantity required ranges from about 54 to 135 l (12 to 30 gal) according to the number of units. Where immersion cleaning is employed in direct-to-churn milking in a parlour, only 22 l (5 gal) of water at 43°C (110°F) is needed for three units.

Energy cost saving in milking parlours

Sources of saving in energy costs need to be viewed as a whole where opportunity allows. They include the following:

- (1) The heat provided by the milk: this is not the biggest item. Tap water used in a plate cooler can be directly used for purposes such as drinking; but main saving of a plate cooler is to minimise load on the bulk tank – possibly by use of chilled water from an ice bank.
- (2) Chief financial saving is through use of an ice-bank created in a separate store during the period of off-peak tariff. This can be used to minimise milk temperature on entry to the bulk tank and to supplement cooling capacity and minimise tank cooling need during day-time milking.
- (3) The compressors which operate the supplementary ice-bank produce a considerable amount of heat at a time when there is no great need for it. Part of this heat can be economically used to assist water heating by means of a thermal store.

In a typical example (e.g. Fullwood DX Power Saver) equipment for all of these purposes is involved.

A commercial unit involving a heat pump can go further towards heat saving in a technical sense. A 4 hp unit (e.g. Mueller Europa 'Fre-Heater') in standard milk-cooling form can produce hot water at a temperature up to 62°C without additional electric heating. In practice the economics of heat saving beyond what can be achieved

by minimising day-time use of electricity depends partly on the extent of need for hot water, either directly or as a contributor to space heating.

Teat spraying

Practical trials show that effective regular disinfection of teats by spraying with a suitable chemical can be an important aid to mastitis control. In-parlour application of proprietary chemicals specially designed for the purpose can be satisfactory if effective application techniques are consistently employed. There is advantage in making the task quick and easy to perform by installing a number of light semi-automated hand-guns. An easily fitted installation (e.g. AMBIC) is vacuum-operated from the milking machine so is available for use whenever needed. The power unit provides chemical under pressure to T-connectors which support the suitably spaced spray guns on retractable coils forming part of the spray delivery lines. A light pressure on the spray release trigger and a sweep of the hand in an arc round the teats can result in effective and economic application.

A fully automated method (e.g. Fullwood 'Fullspray') involves provision of a purpose-designed spray race just beyond the parlour exit, where larger amounts of cheaper hypochlorite solution may be used without health danger to the parlour operator(s). Three spray nozzles are located beneath the leading edge of a 25 cm high slow-down

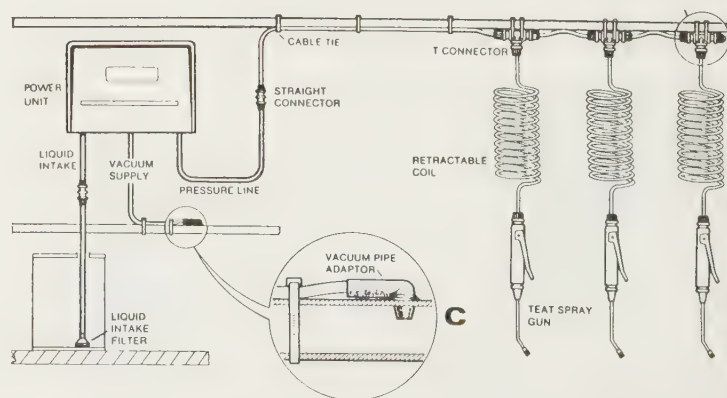


Fig. 20.16 Main elements of hand-operated semi-automated teat spray installation as installed in a typical parlour. (Ambic)

step. Spraying is initiated by photo-electric cells and provides a 1-second burst at 2.8 bar (40 psi). Owing to its location the race may need to be provided with protection against frost.

Cream separators

On farms where a trade for cream exists or where butter is made, the cream is separated by mechanical means. Efficient separation of the butter fat from milk is an important matter, for the total fat is normally around 4%, and a small loss of cream is serious. Separation is effected by taking advantage of the fact that the specific gravity of the fat (0.930) is lower than that of the rest of the milk (average 1.036).

The centrifugal separator accomplishes in a few minutes a separation which is much more efficient than can possibly be achieved by any method relying on the force of gravity alone. The whole milk is rotated at high speed (6000 to 9000 rpm) in a steel bowl, and the heavier elements of the milk pass to the periphery, leaving the

lighter cream near the centre. The process is continuous and with a separator properly adjusted it is possible to reduce the loss of fat to 0.02%.

In practice, a cream containing about 35% butter fat is usually skimmed. Separation should commence while the milk is still warm, as it is then easier and more efficient than at temperatures below 30°C (85°F). If the milk has cooled below this temperature, it should be heated to 32°C (90°F).

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Farm Transport and Materials Handling

It is not always realised what a high proportion of the work on farms consists of the transport of products and supplies such as feeding stuffs, manure and other aids to production. Transport is an important consideration on almost every farm, and on some it accounts for quite half of the total of man and tractor work. It is therefore important that the work should be done with high efficiency. Improvements in materials handling techniques are usually aimed at saving time or labour, or reducing the demands for human energy in carrying out existing operations. It is important, however, to remember that the best way of solving a materials handling problem is often the introduction of a new technique which eliminates the job. A good example is the modern combine harvester, which completely eliminates sheaf-corn handling.

Various principles of materials handling have been enunciated from time to time by work-study experts. The following are particularly applicable to farming:

- (1) Seek ways of avoiding unnecessary handling (e.g. self-feeding of silage).
- (2) Integrate any necessary processing with handling where possible.
- (3) Make efficient use of mechanical power.

The best solution of a particular handling and transport problem depends to a great extent on the nature of the material. Free-flowing materials such as grain or milk are usually most efficiently handled by keeping the material in bulk, and handling it in a fluid condition. Thus, small containers like sacks and milk churns are inevitably superseded sooner or later by bulk handling methods. Non-free-flowing materials such as hay and straw present a quite different problem. At present, a common method is to package the crop into bales – a great improvement on handling in the long, loose form, but far from ideal. Bales of ordinary size were designed

primarily for man-handling, while big-bale systems aim to improve handling efficiency by better use of tractor hydraulics and heavier transport loads. Other methods include chopping to make the material semi-fluid and capable of being moved by blowers or various kinds of mechanical conveyor. A better solution from a materials handling viewpoint is to compress it into pellets, which occupy a much smaller volume and can be handled effectively by many types of mechanical elevator and conveyor. Some materials, such as fruit and vegetables, must be boxed, not only to facilitate handling on the farm, but to provide a suitable package for long-distance transport and marketing. For handling such packages, fork-lifts and other mechanical devices are now available in great variety.

Some of the important aids to farm transport – e.g. front-mounted hydraulic tractor loaders, grain conveyors, bale-handling equipment and livestock feeding equipment – have already been dealt with in previous chapters and are therefore not discussed here. Others, such as universal elevators, are referred to in several places in connection with the wide range of jobs that they will perform.

Factors affecting the draught of vehicles

From the earliest days of wheeled transport the object has been to reduce the draught of vehicles, and the wheels have been designed largely with this end in view. The draught is made up of axle friction, rolling-resistance and slope-resistance.

Axle friction

Provided that bearings are kept lubricated, axle friction is almost negligible on modern trailers. High-grade ball

or roller bearings have a coefficient of friction of only 0.005 to 0.01.

Rolling-resistance

Points which favour a low rolling-resistance are wheels of large diameter, lightness of the vehicles, and tyres and surfaces such that the wheel sinks in as little as possible.

Tests have shown the importance of having wheels of fairly large size: e.g. Swedish tests show up to 10% difference in draught between tyres of 400 and 500 mm diameter (16 and 20 in), and a similar difference between tyre widths of 150 and 175 mm (6 and 7 in). Silsoe Research Institute comparisons showed very large differences when 'standard' 7.50–16 tyres were replaced by 12.50–18. Towing force was reduced by 50% in poor conditions and by 27% in good; and depth of ruts in soft conditions was reduced from 74 mm (2.9 in) to 21 mm (0.8 in). Radial tyres have about 5% less rolling-resistance than otherwise similar cross-ply on most field surfaces.

If one wheel passes over soft land and a second follows, the rolling-resistance of the second wheel is usually appreciably less than that of the first – often only half as great. For this reason it is important that the wheels on four wheeled trailers should track correctly, and also that trailer wheels should follow in the same track as the tractor wheels.

Slope-resistance

When a load is drawn up an incline, the resistance is proportional to the slope. For example, if the incline is 1 : 12, the force required to overcome the slope-resistance is equal to one-twelfth of the weight of the vehicle and the load.

The tractor as a transport agent

Transport is one of the most important functions of most small and medium-powered tractors. They normally operate by pulling trailers, and on soft land the drawbar pull which can be exerted is, within limits, directly related to the weight on the tractor's drive wheels. The main way of increasing the tractor's pulling capacity is use of a pick-up hitch in conjunction with trailers having their wheels well to the rear. Another method is use of a

device for transferring weight by using the hydraulic lift to pull upwards on the trailer drawbar (see Pressure Control, etc., Chapter 2). Tractors can also be used as load-carrying vehicles by fitting various kinds of transport box or platform, but this kind of use is usually restricted to special operations. In some countries of Europe large transport boxes can be carried forward of the rear wheels of a self-propelled tool carrier, but this type of transport has not yet been widely applied in most countries.

Tractor trailers

The most common type of two-wheeled tractor trailer has a platform 3–4.25 m long by 1.80–2 m wide (10–14 ft × 6–7 ft), with the axle placed to rear of the centre, so that the trailer is heavy at the front. The trailer has easily detachable hinged sides and tailboard. This type of trailer is normally fitted with hydraulic tipping and a ring suitable for use of a pick-up hitch.



Fig. 21.1 General-purpose 4-tonne tipping trailer with hydraulic brakes and extension sides. (Marston)

Experience has amply demonstrated the great advantages of the unbalanced trailer system, particularly where the trailer hitch is well designed to ensure ease of coupling.

Two-wheeled hydraulic tippers are suitable equipment for many farms which need to haul sugar beet, potatoes and grain in bulk. Popular sizes tend to increase.

For carting green crops to the silo, a steep angle of tip is important for easy emptying. A 50° angle of tip is provided by some manufacturers, together with a top-hinged rear door which is automatically opened by a linkage during tipping.

Tyre and rim manufacturers specify the maximum loads to be carried by various types and sizes of wheels and tyres; and with a marked trend towards use of large trailers there is increasing need for either very large wheels or the use of more than two. A tandem four-wheel arrangement is usually preferred to use of two very large wheels on general-purpose vehicles for farm work.

High-lift tipping trailers

One type of tipping trailer has the trailer body connected to the chassis by means of a scissor or double-V linkage which can be extended to raise the trailer body to a



Fig. 21.2 A 10-tonne tipping trailer designed primarily for root crops, having tapered monocoque body with automatic up-and-over tail door, sprung tandem axle and hydraulic cam brakes. (Gull Trailers)

height of up to about 3 m (9–10 ft) before tipping. One of the problems involved in use of this type of trailer is the amount of oil needed to extend the multiple hydraulic rams needed for first raising the height of the trailer body and then tipping it. This problem is particularly serious where the trailer is provided with stability legs at the rear, which allow the tractor to be unhitched, leaving the trailer safely tipped for dispensing materials such as seed grain and fertiliser. For such use it is desirable to equip the trailer with an auxiliary hydraulic oil tank and an oil flow system which provides for easy and safe use of the reserve oil capacity (e.g. Adams Hy-Lift).

A difficulty experienced with some tipping trailers, especially those of high-lift type, is that loads of material



Fig. 21.3 Safe high-tip trailer with stabilising legs, hopper divisions and controls for fast easy filling of drills with seed and fertiliser. The tractor may be unhitched and the trailer left tipped. Auxiliary oil reservoir and controls on trailer are used to avoid lowering tractor oil level. (Adams Wagons)



Fig. 21.4 Hydraulic drive auger with remote hand control used for filling drill. (Rekord/Jema)



Fig. 21.5 The hydraulically operated bulk hopper can replenish the fertiliser distributor on the move. (Deutz/Hassia)

such as silage may fail to slide out, with the result that the centre of gravity moves to a point behind the trailer axle and can cause vertical jack-knifing. This can and should be prevented by suitable trailer designs, some of which are discussed below.

A variation of the usual high-lift-and-tip system is a high-lift, tip and set-down system which allows the trailer

chassis to be withdrawn, leaving the trailer body set down, supported on legs, in such a way that material contained in it can later be emptied from it as needed.

Trailer hitches

The advantages of the hydraulic pick-up hitch are so obvious that this general method of hooking up to trailers is certain to continue to supersede hand-hitching methods. A tractor equipped with hydraulic pick-up hitch can be coupled to the front-heavy trailer without the driver having to step down from the tractor. The tractor carries a hook which is coupled to the hydraulic lift linkage. The tractor backs up to the trailer until the hook is beneath an eye at the front of the trailer drawbar. On raising the hydraulic lift, the tractor hook engages with the eye on the trailer, and the hitch is securely locked as soon as the drawbar is fully raised.

The basic Ferguson 3-point linkage and pick-up hitch system were adopted early as British Standards, fairly soon endorsed by ISO. Today, BS 5891:1980 (ISO 5692) specifies 'Ring type hitches on agricultural trailers and towed implements': and in response to practical needs, a recent ISO standard (6489-1 1991 E) *Agricultural Vehicles – Mechanical Connections on Towing Vehicles*, Part 1, Hook type, specifies in Para 4 *Location*, the hook position in relation to clearance zone at the end of the pto shaft specified in ISO 500. A British Standard specification, BS 6139:1981 for drawbars and towing hooks on agricultural tractors under 4.3 vertical load capacity, states 'The manufacturer shall declare the static vertical load capacity of the pick-up hook, taking account of the tractor tyres and conditions of use'.

Unbalanced trailers of above 10 tonne capacity can usefully incorporate a sprung drawbar to reduce the effect of shock loads. The drawbar pivots at the rear end and is supported by stiff leaf springs. As the load on the standard pick-up hitch is increased by use of bigger trailers it becomes increasingly advantageous to move the point of application of the load on the tractor to a position beneath or slightly forward of and beneath the rear axle, while providing for safe articulation in all three planes. A hitch conversion (Poole 'AN-T-FLIP') to fit on standard three-point linkage lower links is designed to put the trailer drawbar load on the front pivot points, which are in fact usually slightly to rear of the axle centre. An X-frame

and vertical-pintle coupling are attached to the links, and the tractor hydraulics set at 'release'. Trailer drawbars must be adapted to receive the drawbar socket, and a suitable goose-neck fitted to maintain the correct angle on the main trailer drawbar.

Four-wheeled trailers which are widely used in many European countries have a ring hitch designed for use with a clevis that is located higher than the tractor axle. Such hitches are for road transport, and can cause dangerous rearing of the tractor if misused.

On four-wheeled vehicles it is often convenient to have at the front of the drawbar a short swinging arm which is telescopic until locked.

Avoidance of vertical jack-knifing

There are two main ways of minimising or eliminating danger from vertical jack-knifing when top-heavy loads are tipped. One method is to provide a trailer body that is smooth inside and is appreciably wider at the rear than at the front, with the object of making it easy for the load to slide out before its centre of gravity is behind the axle. A more positive method is to provide a strut far enough to the rear of the axle to ensure that the centre of gravity has to go very far to the rear before there can be any lifting effect on the trailer drawbar. Both methods can be used with advantage. On one manufacturer's silage trailers the short anti-jack-knifing leg is operated from a hydraulic feed-pipe connected to the main tipping ram. The ram on the leg is smaller in diameter than the main ram, and this ensures that it is extended first.

Where tandem articulated twin axles are employed, a linkage can be devised to ensure that the points of contact with the ground during tipping are the rear pair of wheels.

Trailer brakes

Use of tractors and trailers on the highway is regulated by individual countries in varied ways, influenced by both historical factors and international agreements such as those between member countries of the EC, and on a wider basis by participants in work of the Road Transport Committee of the UN Economic Commission for Europe (ECE). Most countries require effective brakes to be fitted to any agricultural trailer of a useful size, and some have regulations that specify in detail how the braking

system shall operate. In Britain, the Motor Vehicles (Construction and Use) Regulations apply: these are amended from time to time in accord with international undertakings. UK Regulations do not dictate the system of operation of power brakes for Agricultural Motor Vehicles (term defined in Construction and Use Regulations, which includes conventional farm tractors) whose maximum design speed does not exceed 20 mph. For trailers towed by such tractors having gross weight 750 to 18290 kg (and agricultural trailed appliances up to 14230 kg gross weight), use of a standardised, already widely used, single-line 'power-on' modulated hydraulic braking system is recommended. The C & U regulations require standards of efficiency and performance including a braking force of not less than 25% of the *actual* weight of the trailer or trailed appliance. Other effective power systems including air brakes are allowed. It is expected that leading tractor manufacturers will increasingly offer, as options or as standard, provision of the necessary valves in the tractor's built-in hydraulic system, to ensure that when the appropriate hydraulic connection to the trailer or machine is made and the tractor brakes are applied, those on the trailer will operate slightly ahead. In the meantime leading trailer manufacturers offer appropriate bolt-on valve assemblies, with the necessary connections and controls, for use where built-in tractor components are not available.

For 'fast' tractors which exceed 20 mph (e.g. Unimogs, JCB's new HMV and M-B Tracs), maximum speed is restricted to 64 km/h (40 mph) and new vehicles have to meet *all* normal road transport vehicle requirements. If these fast tractors tow a trailer at over 20 mph, the trailer braking is subject to compliance with the regulations for a goods-carrying road trailer; in practice this means use of a two-line fail-safe air braking system.

Four-wheeled tractor trailers

Four-wheeled trailers are advantageous where bulky loads have to be carried and a large platform is needed. They are easy to hitch, can be safely left loaded and are particularly useful for long road journeys. Their chief disadvantages are the extreme difficulty of backing them, and tractor wheel slip in difficult conditions if weight transfer devices are not provided. Some four-wheelers have a turntable which necessitates the platform being high

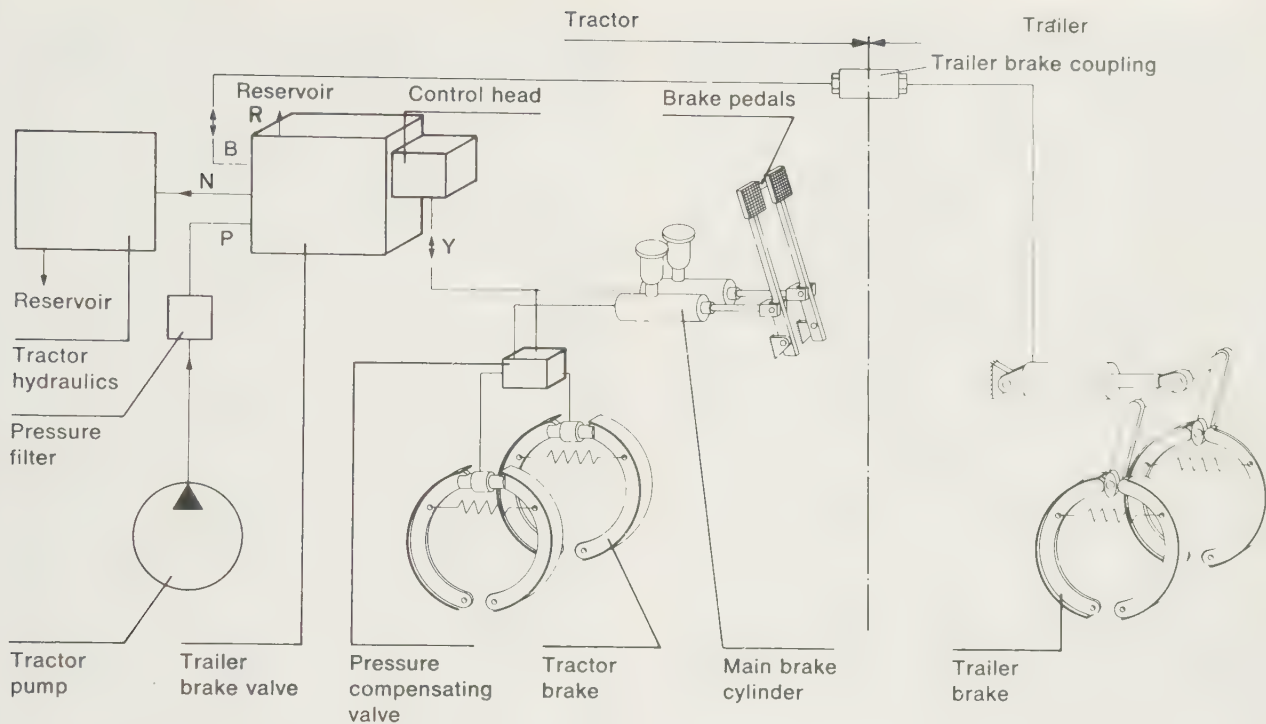


Fig. 21.6 Single-line hydraulic trailer braking system: general design. (Bosch)

The trailer brake valve is incorporated in the tractor hydraulic system. It provides graduated power braking with priority, high power density and short response time (approx. 0.05 sec), so that trailer brakes are applied just before the tractor brakes. (See also Fig. 2.30.)

enough to allow the front wheels to pass beneath it, but automobile-type steering is now widely used, and if well designed it combines the advantages of a good lock with stability. Hydraulic side-tipping four-wheeled trailers are available.

There are great advantages in a telescopic hitch. Tests in the USA have shown that such hitches not only save time but also help to avoid accidents.

Pto-driven trailers and tankers

Tests carried out in Sweden with trailers having a power drive to the wheels have shown that tractors of over 25 hp drawing balanced two-wheeled trailers are much more effective in difficult ground conditions if the power drive is engaged. In fact, the loads that could be hauled were found to be two to three times as great in extreme conditions. However, it should be noted that fitting wheel girdles to the tractor improved performance by about 50%, while fitting half-tracks doubled the effective pull.



Fig. 21.7 The JCB High Mobility Vehicle with full suspension and air brakes can haul up to 14 tonne loads at 40 mph in a suitable tandem axle trailer engineered to highway duties specification matching that of the tractor. (JCB HMV)

Moreover, with a light tractor and a two-wheeled trailer which had the axle near the rear end, very little advantage was gained by driving the trailer wheels.

When a pto-driven trailer is used, the drive to the trailer wheels should provide the same land speed, or one a little slower than that of the tractor. The trailer wheels should never be driven at a faster forward speed than the tractor's. As a general rule, the pto drive is arranged for use when the tractor is in low gear, and it is only engaged in specially difficult conditions.

Hydrostatic power drive is offered for use on equipment such as large slurry tankers that may need to work on soft and sloping land. A variable-delivery pump mounted on the vehicle is pto-driven. It powers wheel motors with a free-wheel ability, enabling the vehicle to be towed at normal road speed when the assisted drive is not required. Such drives are used mainly at speeds up to about 10 km/h (6 mph).

A mechanical trailer wheel drive mechanism (e.g. TruSpec Traction-Drive) has been developed for use by wheeled tractors to provide a reliable drive to suitably-tired heavy-duty trailers or tankers working on slopes in slippery conditions. The drive mechanism consisting of a pair of small-diameter traction cage wheels has bars to match the tractor tread pattern; it is attached to the tractor by the three-point linkage and pressed into or out of engagement with the tractor tyres by a double-acting ram in the top link. The cage wheels drive a central differential gearbox which has gearing individually selected to provide the right ratio between the tractor and the driven vehicle tyres. Any suitable tractor gear can be used, since the gear has no effect on the fixed ratio needed to make the trailer tread run slightly more slowly than that of the tractor drive wheels.

Tractor and implement transporters

The transport of tractors and other heavy equipment is often a serious problem, and various types of pneumatic-tyred trailer are employed for this purpose. Such trailers need to have very low platforms so that tractors can be driven straight on, and heavy implements such as disc harrows may be pulled on by means of a hand winch attached to the trailer.

The simplest type of tractor transporter is a two-wheeled trailer with the bed mounted directly on the axle, and

consisting merely of two members which are correctly spaced and are just wide enough to accommodate the tractor wheels or tracks. A hinged ramp is provided at the rear, and this is raised for travelling. Jacks are provided at the corners to steady the trailer during loading. Such two-wheeled transporters can only accommodate tractors of moderate weight. For only slightly heavier tractors a somewhat similar four-wheeled trailer with the two axles set close together may be used. Many modern implement transporters employ a pick-up hitch at the front and a hydraulically operated cranked connection between the implement platform and the axle at the rear. This enables the carrier bed to be lowered flat on the ground for loading. The tractor can run across it to locate the implement, and can then use its pick-up hitch and external hydraulic power to raise the platform for travel.

A heavy-duty tandem-axle low-load vehicle has been specially developed for such purposes as transport of a large tracklayer and its mounted six-furrow reversible plough. The long platform is hydraulically tilted by the external hydraulics of a wheeled tractor until the rear edge rests firmly on the ground. At the same time the front trailer axle is moved forward and locked in position to provide a stable low-angle ramp. The tracklayer with its mounted implement is driven up the ramp, the implement lowered, the platform returned to horizontal position and the front axle retracted (e.g. Jones 'Hydratilt'). The trailer can also be used with the towing tractor removed as a ramp for lorry loading.

Specialised transport vehicles

Four-wheel-drive vehicles are valuable for transport work over fields or rough farm roads, especially in hilly conditions. Smaller four-wheel-drive vehicles, e.g. the Land-Rover, etc., which weigh a little over 1 tonne and are designed to carry $\frac{1}{2}$ tonne, are invaluable for light transport in difficult conditions. They can traverse rough land and have a good capacity for keeping going on uncultivable land. They can be used for light field work – e.g. light rolling and harrowing, mowing, spraying, etc. – and also for light belt-work. Their primary function is, however, the transport of men and of small loads over difficult roads or over fields. In addition to these, which are primarily personnel carriers, there are vehicles with large wheels which are intermediate between these and tractors

(e.g. Unimog). The Unimog is particularly suited to jobs which require a combination of road transport and field work, such as applying liquid fertilisers. Such vehicles are not well suited to work such as ploughing, but can do a limited amount if necessary.

A type of tractor/transport vehicle giving priority to the needs of high-speed transport (e.g. 'Trantor') incorporates chassis springing and four-wheel braking, with power braking for trailer. The chassis has independent front springs and rear leaf springs with dampers. Imposed trailer weight carried on a pick-up hook is transferred to the chassis via a heavy horizontal leaf spring. Air brakes provide for a two-line service to the trailer. Traction capabilities are limited by tyre sizes, but road speeds with trailer can be up to 40 mph while higher speeds may be employed when the vehicle is used alone as a personnel carrier or light truck. When a front loader is used a beam is inserted to fix the front suspension height. For heavy drawbar work the hitch spring is similarly locked out of action. In some German designs which provide for high-speed road transport, advanced design features found in conventional tractors in highly mechanised countries are also included. This makes the vehicles complex and expensive, and inevitably throws doubt on the economic justification for choosing a vehicle with such a wide range

of speeds, as well as catering for normal tractor field work. Lightweight self-propelled vehicles with a large number of very-low-pressure wheels have been developed as personnel carriers or small load carriers, for operation as self-propelled sprayers, and for light draught purposes such as pulling a suitably designed trailer to carry a granular fertiliser distributor (e.g. Argo). A typical vehicle with eight driven wheels has a very low centre of gravity and adequate track width and wheel-base to operate safely on steep slopes that are reasonably free from large obstacles. Other types of low-ground pressure vehicles, including motorcycle ATVs, having sufficient traction for major field operations such as spraying and distributing on soft cultivated land are dealt with in Chapter 2.

Tractor hydraulic loaders

The performance of tractor front loaders depends primarily on the power available from the tractor's in-built hydraulic system and ability to apply this power easily to a variety of farm handling tasks. Effectiveness of appli-



Fig. 21.8 Multi-purpose eight-wheel drive transport vehicle with 691 cc twin 4-stroke engine and power transmitted through torque converter into a HI-LO transmission and reverse. Vehicle has very low ground pressure and towing attachment for use with trailer or trailed engine driven distributing equipment. (Crayford Argo)



Fig. 21.9 'Toe-tip' bucket, seen on four-wheel-drive tractor loading sugar beet, considerably increases maximum practical loading height compared with bottom hinge type. (Howard G. B. Farmhand)

cation depends to a large extent on the tractor's conformation: small un-driven front wheels normally have a very limited load-carrying capacity. The trend to four-wheel-drive makes it easier to carry a big load at the front, and to work on rough or slippery land.

'Conventional' tractor ranges of leading manufacturers become progressively more suited to front-loader work. Specialist loader manufacturers have met a need to provide a choice between maximum load and speed of lift by providing a choice of hole positions in the plates attaching lift rams to the loader beams; and in a similar way a choice of location of fixing holes for tilt rams gives either maximum tear-out force or higher speed (e.g. Farmhand 'Gyro'). An easy way of providing the choice between maximum load and speed is by a suitable valve in the plumbing system: in a typical range (e.g. M-F 80 loaders on 200 and 600 Series tractors) the choice is a fast (6 seconds) lift of a small maximum load (about 750 kg) or slow (12 seconds) lift of a maximum load over twice as big. A 'toe-tip' bucket on a heavy-duty type loader can

appreciably increase maximum loading height (Fig. 21.9). Maximum lift in current MF 888 Series on 300 or 3000 Series tractors with standard parallel linkage is 2002 kg lift to 4.06 m; this may require extra weight on the rear linkage. Tractors of conventional conformation usually have appreciably more load-carrying capacity on their large rear wheels than on the front; and experience with some reverse-control consoles of European origin shows that it is possible for multi-purpose tractors to provide very good vision and control for a rear-facing operator, and to compete on rough-terrain loading work with more specialised handling vehicles. This, however, depends on the reverse console being part of a thoroughly researched and developed overall vehicle design.

The versatility of any loading vehicle is improved if adequate provision is made for easy change of attachments. It is an advantage if an unaided driver can also easily and safely put on and take off the tractor loader itself. This is often aided by providing a stand to ensure that on a level surface the loader can be securely parked in a 'drive-in'



Fig. 21.10 Grab for manure or silage used to remove upper layers from silo before self-feeding. Grab comprises eight lower tines 600 mm long at 180 mm centres, side tines as needed, and three upper grab tines operated by two double-acting hydraulic rams. (Twose)



Fig. 21.11 A four-wheel-drive tractor with reverse console operating heavy-duty loader with root cleaning bucket. Mounting of loader above load platform provides good visibility. (MB-trac/Baas)



Fig. 21.12 Wheel-supported linkage-mounted tractor fork-lift with 2 tonne load capacity. (*McConnel Ripvator*)

position. The necessary basic connections remain on the tractor, and good designs provide for use of easy hydraulic power to pick up the loader.

Loader forks and buckets

The range of forks, grabs and buckets available for use with tractor front loaders has been greatly extended under the stimulus of four-wheel-drives and competition from specialist rough-terrain handling vehicles equipped with a variety of patented 'Quick-fit' powered back-plates. The 'Portec' Triple Loader is the result of an individual user's

wish to combine in a single attachment ability to perform the operations normally carried out by (1) a fork with eight fairly long tines and a solid back shaped to hold some short material if tipped rearwards during the lift; (2) a grab with interlocking tines able to squeeze and pull upwards fluffy, soft materials; and (3) a bucket capable of holding friable soil, sand or gravel. All of these objectives are achieved without leaving the tractor cab by simple partial or full hydraulic folding of the upper, short-tine hinged section of the Portec loader illustrated in Fig. 21.13.



Fig. 21.13 'Triple' Front Loader attachment with in-cab operated hydraulic folding of the hinged upper member to change the purpose from long-tine-fork, via fork with retaining grab for soft fluffy materials, to large-capacity bucket for soil, sand or ballast, and vice versa. (*Portec UK*)

When the loader attachment is fully folded, both sets of tines have their points sheathed by and fully supporting the opposite section of the bucket.

When handling silage the main (lower) forks are driven into the face horizontally at a depth just sufficient to leave the top undisturbed by the upward lift.

For slurry the bucket can be completely closed after entry with the bottom fork horizontal: the overlapping edge plates make a good seal. The attachment earned an RASE Silver Medal award in 1990. (*'Portec' UK Triple Loader*)

Industrial loaders

Second-hand industrial loaders can find useful employment on farms when fitted with a large-capacity fork for filling and emptying silos, as well as for manure loading and more general loading work using a tipping bucket. Features that make them successful include large wheels with four-wheel-drive; high power; a transmission suited to fast loader work, and a heavy load capability.

Another type of vehicle also developed primarily for industrial purposes which finds some application in agriculture is a smaller four-wheel-drive skid-steer loader. Such vehicles are primarily suited to work on firm and level surfaces. Their main attraction is ability to turn in a very small space though tyre wear on typical farm concrete surfaces can be a drawback.

Tractor-mounted fork-lifts

Development of box and pallet handling on farms began with the use of industrial fork-lift trucks for work in and immediately adjacent to farm and horticultural buildings. Limited use of tractor operated fork-lifts followed, but this was a quickly passing phase, affected mainly by the rapid development of specialist rough-terrain handling vehicles, especially the progressive adoption of four-wheel-drive with hydraulically extending telescopic booms plus parallel lift, followed again by all-wheel steering, ROPS and FOPS tests for cabs and every possible advantage taken of instrumentation to avoid overloads which could be injurious to the operator or bystanders.

Some exceptions to the general trend are explained by saving of capital cost, as in the case of the wheel-supported



Fig. 21.14 Conventional mast-type RTFLT stacking big bales in barn. Counter-weight assists in providing stability in high-lift situations. Good operator visibility and ease of control are normal design aims. (*Bonser*)



Fig. 21.15 Articulated steer four-wheel-drive telescopic-boom handling vehicle of low overall height with boom lowered, using general-purpose fork to fill clamp silo. (*Matbro 'Telaram'*)

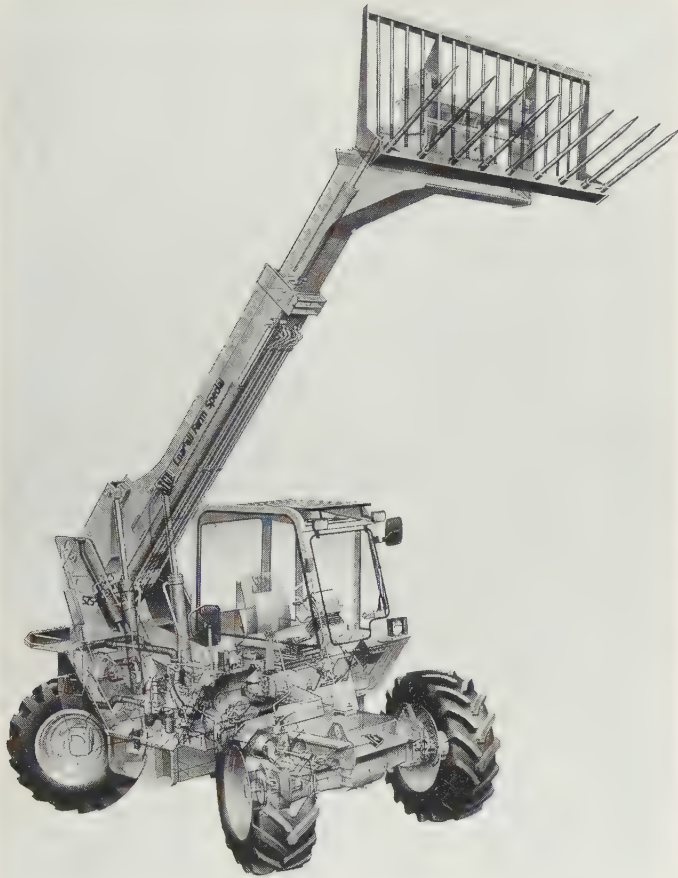


Fig. 21.16 Sectional cut-away view of Loadall Farm Special with general-purpose fork on Q-fit carriage, four-wheel-drive, all-wheel steer, Model 525-67. (JCB)

tractor linkage-mounted fork-lift, invented by a farmer. The mast in such use is mounted close to the tractor and using mainly the linkage attachment points at the tractor end, but not the standard linkage. Power for the lift is from the tractor's external hydraulic service. The main use of the wheels is to avoid having to add very heavy weights to the front end of the tractor. The minimum front ballast needed is about one third of the load weight. Such tractor fork-lifts can be satisfactory for box and pallet handling with loads up to about 2 tonnes (depending on tractor size) and lifts up to about 4 m. Additional front tractor weight is essential when heavy loads are lifted. The minimum front ballast need is about one third of the load



Fig. 21.17 Telescopic boom handling vehicles with four-wheel-drive and steering can make tight turns or move crab-wise on heavy manure handling work in yards originally built for use of hand forks. (Sanderson Teleporter 2)

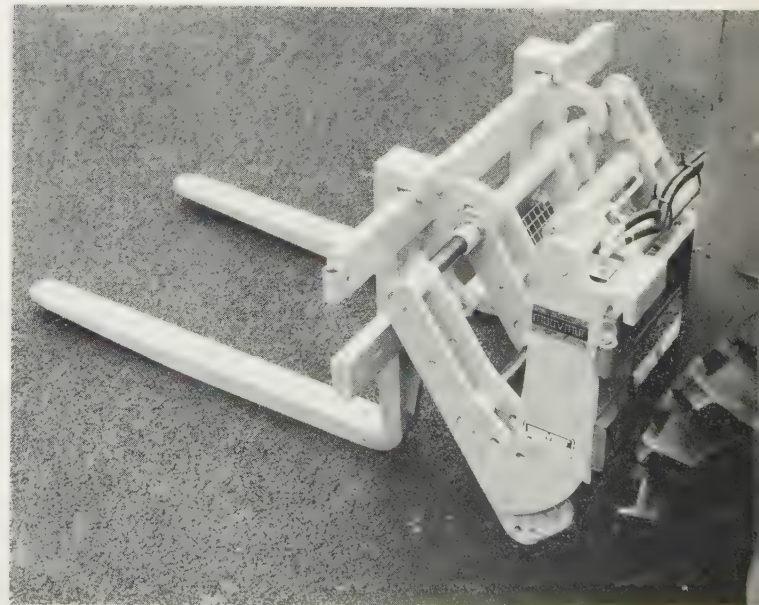


Fig. 21.18 Power-hitch with built-in side-shift picking up pallet fork. (Moovmor)



Fig. 21.19 Quick-attachment mechanism. Bucket is first raised by pair of hooks and then tilted back. Lower pins are inserted by use of hydraulic control in cab. (Sambron)

weight. One type of fork-lift with a conventional mast is attached to the three-point linkage for easy mounting and removal, and uses a pair of transport wheels at the foot of the mast to support the load (McConnel 'Ripvator' (Fig. 21.12) and 'Stackvator').

Rough-terrain handling vehicles

Applications

In considering what type or types of handling vehicles are needed it is worthwhile first to list the jobs to be done and the conditions in which the vehicle will be required to work. There may be specialist fork-lift work in buildings such as high stacking of boxes in a potato store that necessitates use of an industrial-type fork-lift truck with cushion tyres: such needs are not considered here. A normal range of tasks may include:

Work with flat forks: On flat pallets – bags of fertiliser and seed; seed potatoes in trays; vegetables in boxes: all on soft soils as well as at buildings.

In box pallets – potatoes and root vegetables: picked up in fields and stacked or emptied at store.

In palletted hoppers – animal feeds: usually at buildings.

Work with tined forks: Loading manure; handling green crops for silage; removing silage for feeding; handling big bales; some surfaces, e.g. on clamp silos, may be very soft. Choice of forks, with grapple, push-off, etc., needs care.

Work with tipping buckets: Bulk loading of grain, roots, slurry and occasionally soil.

Work with squeeze attachments: Handling big bales and groups of bales, including high stacking in buildings.

Work with crane hooks: Handling fertiliser in big bags.

Work with specialised attachments: An example is a silage block cutter.

Handling vehicle types

When specialist handling vehicles were first used by growers and farmers, it was mainly in and about the buildings on hard and reasonably level surfaces; the main type had a rigid chassis with a mast-type fork-lift and small-diameter solid rubber wheels. The main use was in stacking of pallets and boxes. The need for rough-terrain vehicles developed rapidly, and some were soon equipped with grabs to compete with tractor loaders. For much of the outside work, pivoted booms became attractive; and the telescopic-boom type was later quickly appreciated and accepted for a wide range of uses. Development of new attachments flourished, and needs such as climbing steep and soft slopes in silage-making or working in slurry lagoons soon emphasised the value of high-powered, high-clearance specialist vehicles. The variety of types of vehicles now available justifies a careful study of needs and equipment.

RTFLT choice considerations

Engine power and transmission: It is not to be expected that a vehicle of less than 37.5 kW (50 hp) can out-perform a large tractor on many loading tasks. Typical power need per ton of rated lift capacity is about 19 kW (25 hp) for small and medium-sized vehicles. For many agricultural purposes a good synchromesh transmission can be satisfactory, but torque-converter transmission may be preferable if there is a great deal of continuous shunting to be done. Work rate is dependent on hydraulic power, which controls lift and lower speeds: 0.3 to 0.45 m/sec is a typical lift speed on a specialist vehicle.

Lift capacity and lift height: Rated lift capacity is a question of both power and safety. It depends on distance from the centre of gravity of the load to the point where the lift force is applied, e.g. the mast. With agricultural RTFLTs this is typically 0.5 to 0.6 m. When loads are raised stability is appreciably affected by the angle of tilt. Specified lift capacity relates to the specified maximum lift height, and this is related to safety factors including overturning danger. There is a steady and marked reduction of capacity with increase of lift height. Capacity is de-rated by the weight of complex attachments: for example, the rotator for a 1 tonne box may knock $\frac{1}{2}$ tonne off rated capacity, compared with a simple fork. With telescopic-boom vehicles there is a sharp reduction of lift capacity with increasing extension. Thus, a vehicle with maximum lift of 2 tonnes has a capacity well below 1 tonne at maximum extension.

Types of mast: For much farm work there is a need to work easily in low buildings. It is also advantageous to have a 'free-lift' capacity which enables the load to be raised and lowered up to a reasonable height without the mast itself being raised. Triplex masts provide a high maximum lift coupled with a low closed height and a useful free-lift capacity. In considering required lift heights it is necessary to allow for avoiding fouling vehicle sides when the fork or bucket is tipped. Box stacking and good pallet handling require good control of side-shift and tilt: so an attachment providing this should be considered. High stacking in buildings needs a specialist mast-type vehicle. Particular advantages of all types of telescopic boom are the ease with which loads of limited weight can be stacked on or unloaded from the far side of a truck, and ease of stacking well beyond barriers into the recesses of buildings.

Attachments: Ease of fitting a variety of attachments can be an important need. There are many patented designs, and farmers' organisations have expressed a justified desire for a study of standards for promotion of interchangeability. A powered back-plate makes it easy to pick up attachments that are parked on a hard, level surface. Most make use of the principle of lifting the attachment by means of a pair of hooks. When raised the attachment swings to a position where the lower fixing pins are in line with the holes. The pins may on some machines be inserted by hydraulic power from the driver's seat. Where a loader of restricted boom length gives insufficient clear-

ance for loading high-sided vehicles, a bucket with a powered tipping ram of 'high-tip' or 'toe-tip' type can often easily provide the extra clearance needed. When choosing a multi-purpose fork, possible needs may include feeding silage and handling bales as well as manure loading.

Traction capability: Traction problems can easily arise on very soft surfaces such as chopped grass in a clamp silo. Since much of the difficulty arises from sinking of heavily loaded steering wheels, larger driven wheels can often bring substantial improvement. One of the reasons for poor performance of drive wheels is the high inflation pressure necessary to support vehicle and load weight: this may be over twice that of typical tractor tyres of similar size. Best traction performances on soft surfaces such as silage clamps are usually provided by vehicles having a reasonably high power-to-weight ratio and employing four large equal-size driven wheels. A clean design to provide smooth under-belly surfaces and good ground clearance are essential.

Battery- or engine-operated lift trucks

Self-propelled fork-lift trucks with capacities of up to 1 ton or more and lift heights up to above 6.1 m (20 ft) are used in large fruit and potato box stores. They are generally designed for short-range duties on smooth, hard surfaces. Cushion tyres are best where the work is all on concrete, but pneumatic tyres may be preferable where the truck has to run on surfaces such as cinder roads. The maximum gradient for a typical loaded truck is generally about 1:8. Speed of battery-operated trucks may be up to about 11 km/h (7 mph), but some engine-driven machines go up to about 16 km/h (10 mph). Self-propelled fork-lift trucks are much more manoeuvrable than tractor fork-lifts, and are therefore more suitable for use in confined spaces such as refrigerated stores.

Safe use of fork-lifts

Whatever the type of fork-lift, it is essential when handling heavy loads to take care to keep the load as low as possible when on the move, and to utilise the tilt of the mast to keep the centre of gravity of the load as close as

possible to the vehicle. It is also necessary to use brakes carefully, since a heavy load has a considerable tendency to overturn the truck.

Steering characteristics of some rear-wheel-steered vehicles compare unfavourably with those of front-wheel-steered tractors: a road speed capability above 20 km/h should therefore be used with discretion, especially when carrying a load.

Bulk handling of feedingstuffs

Where intensive livestock units use large amounts of purchased feeds, bulk handling is almost essential. The normal arrangement where ready-prepared feeds are used is to station the self-emptying bulk bin at the end of the livestock building, and to fill it direct from the merchant's vehicle. The bins should preferably hold about 25% more than a typical bulk load, so that deliveries can be conveniently and economically arranged. Some merchants offer special terms for purchase of the bins, with repayments spaced over a period of about two years. The normal method of discharge from the road transport vehicle is by pneumatic conveyor. Many vehicles are equipped to carry two or more different feeds in separate compartments. Some vehicles use auger delivery. Advantages of this are less noise and a lower power requirement. To avoid degeneration of the feed, delivery rates are usually limited to about 15 tonnes/hour. The slewing delivery boom is able to discharge at a height of up to about 6 m (20 ft).

Universal elevators and loaders

Reference has already been made to special-purpose elevators for loading bulk potatoes and sugar beet. General-purpose elevators usually consist of a simple conveyor of chains and slats, running on a bed which may be solid or in the form of a grille. A hopper and cleaning mechanism can be fitted at the base for handling crops such as sugar beet. The angle of the bed is usually adjustable: alternatively, the end section of a long elevator may be hinged and adjustable to suit various loading heights. The small machines are usually carried on two pneumatic-tyred wheels, but some machines with a high lift have four wheels. The engine or motor, usually of



Fig. 21.20 Specialised handling capabilities of telescopic-boom vehicles can include a rotary box tippler for gently emptying potato boxes. (JCB)

1.1–1.5 kW ($1\frac{1}{2}$ –2 hp), is mounted on the chassis beneath the elevator.

Many modern sack and bale elevators are easily adjustable in height at the lower end, as well as at the upper end. Provision of this facility makes it easy to take bales directly from the top of a load.

Pneumatic conveyors

Pneumatic conveyors are mainly used in Britain for the handling of grain and meal, and their use for grain conveying is dealt with in Chapter 18; they may also be used for bulky materials such as hay and straw. The principles of operation are simple, but application may be very varied. It is necessary to provide a high-velocity air-stream capable of lifting the material and holding it in suspension. To do this, there must be a minimum airspeed suited to different materials, and the quantity introduced into the conveyor must be regulated to avoid overloading.

Feed merchants choose pneumatic delivery for grain, cubes or pellets on account of its flexibility. The blower is driven by pto, and the rotary valve feeder may be kept supplied by hydraulic tipping where necessary. At delivery heights normally required, rates up to 20 tonnes/h can be achieved.

A type of pneumatic conveyor developed in the USA can deliver meal through small-bore pipes over long distances. An auger is used to introduce the meal into the air-stream produced by a compressor, and delivery is typically by means of 50 mm (2 in) bore pipe-work. This is suitable for distributing feed from a central food-preparing plant to bulk bins at the ends of a number of livestock buildings.

Most forage blowers for filling tower silos operate as impellers. They rely on passing the forage through the impeller/fan, in order to provide the initial momentum. It is, of course, essential to maintain the conditions required for pneumatic conveying, chief of which are an adequate airspeed and ratio between the amount of air and amount of crop handled. A second requirement in conveying forage is avoidance of roughnesses or bends which tend to cause the crop to be caught up and lead to blockages. With any pneumatic conveying system, there is always a problem at the delivery end, in releasing the crop from the air-stream and allowing the air to escape. For this purpose cyclones are widely used to assist separation of light materials. In conveying forage crops there are, however, many circumstances where use of cyclones is not practicable. The building or container then needs to be designed in such a way that easy escape of the exhaust air is provided for. For example, when a high-capacity blower is used to propel forage into a sealed tower silo, it must be realised that both conveying and distribution will be inefficient unless an adequate air

escape, preferably some distance from the inlet, is provided.

Transport in the farmyard

The aggregate importance to British agriculture of mechanisation of transport about the farm buildings can hardly be over-emphasised. Efficient mechanisation usually involves planning to eliminate unnecessary movement of materials, and to make arrangements designed to cut down distances travelled and difficulty of the work. Many buildings were not designed for their present uses, and there are often economic limitations to the amount of remodelling of farmsteads that can be undertaken. Nevertheless, it is frequently better to tackle the problems by drastic reorganisation rather than by using mechanical gadgets to overcome the difficulties of layouts which are fundamentally unsound for present needs.

Much can often be done by opening up gateways and passages so that tractors and trailers can be used, and there are many farms where it is possible to achieve substantial economies in transportation by making smooth, concrete feeding passages, and introducing such simple aids as rubber-tyred feed barrows. The value of a piped water supply in saving transportation is now widely appreciated.

References

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- Agricultural Safety: Agricultural Trailer Braking Systems*
Health and Safety Executive.

Machinery for Land Drainage, Reclamation and Estate Maintenance

Developments in specialist tracklaying excavators worldwide and an illustration (Fig. 22.1) of a British hydraulically operated long reach river rig are a reminder that farmers' responsibilities for their own drainage problems are often dependent on continued maintenance work by area Drainage Boards or their successors. This chapter deals primarily with the equipment used by farmers and agricultural contractors, and includes, in particular, developments in hedge and verge cutting equipment.

Ditching equipment

Many types of tractor-mounted ditcher have been developed, and they range in complexity from a simple scoop that is connected to the usual hydraulic-lift linkage of a wheeled tractor, to complex power-operated attachments.

The wide range of agricultural loader/diggers includes machines that mount on the three-point linkage, with stabilisers; machines with a specially designed quick hitch

Fig. 22.1 Standard tracklaying Super Hydraulic Excavator equipped with power-slide long-reach river rig giving 15 m (50 ft) maximum reach and 4 m (13 ft) depth, fitted with wide desilting and bank clearing bucket. (JCB 818 ReachMaster)

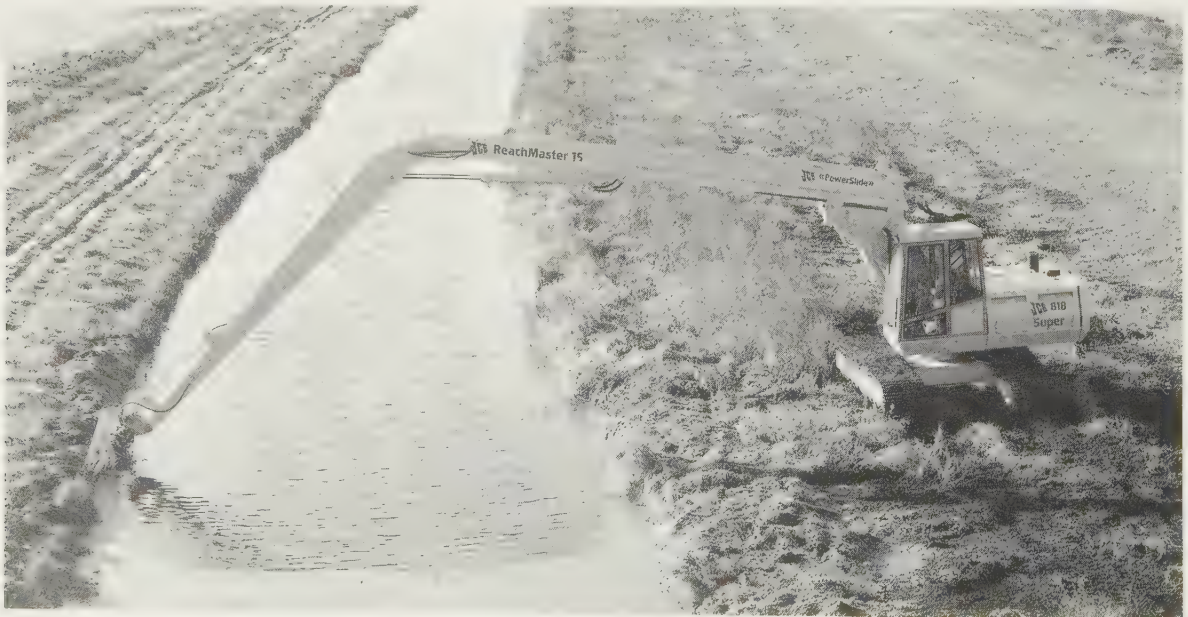




Fig. 22.2 Ditching with multi-purpose hydraulically powered tractor-mounted machine. (McConnel)



Fig. 22.3 Light-industrial excavator-loader with extending dipper. With swivel-post offset as illustrated the excavator can effectively carry out maintenance on small rivers from one bank only. (JCB)

of a 'snap-on' type; and others that require a substantial subframe to be bolted on to the rear of the tractor.

The quick-hitch type has obvious advantages for multi-purpose machines. The frame is supported by a pair of widely spaced sprags that have independent hydraulic adjustment and carry the whole weight of the rear end of the tractor and equipment when digging or loading.

It is a considerable advantage to have easy lateral adjustment of the king-post, to allow good trenching work to be done on an offset line, and to increase the reach to one side. There is also a considerable advantage in a large slew angle, since this enables the outfit to do more work at each move, and improves its versatility.

Versatility is also increased by provision of separate booms for digging and loading. Alternatively, or additionally, the slewing boom can be attached to the king-post in different positions to provide variation in maximum loading height or digging depth.

Naturally, when the equipment is set for maximum loading height, the maximum lift force is considerably less than when loading height is restricted.

The smaller-capacity loaders are usually operated by the tractor's normal hydraulic system. A satisfactory performance requires a minimum of about 22.5 l/min (5 gal/

min) at a pressure of about 155 bar (2250 psi). Where a tractor cannot provide this amount of hydraulic power, a pto-driven hydraulic kit with its own separate oil tank should be provided. This adds considerably to cost, but allows work to be speeded up. For high-speed work with the larger outfits, 45–50 l/min (10–12 gal/min) of oil is needed. It is the difference in hydraulic power available which partly accounts for differences in the speed of work with different outfits.

Other features which should be studied are the ease of fitting to the tractor, ease of control, ability to slew sufficiently for all reasonable needs and ability to work effectively near obstacles, including cab roof members. As a general rule, the light-industrial-type loader/diggers are more powerful than light agricultural machines, and they are much more permanently fixed to the tractor. On most farms it should be no more than a 10-minute job to hitch up to the machine or to remove it from the tractor; this is impossible with the industrial-type equipment.

Skill in operation of a loader/digger comes from sound instruction plus experience. A skilled operator can work in ways that would be impossible for a novice. For example, when some machines are engaged on ditching or trenching, the tractor can easily and quickly be moved along by the



Fig. 22.4 Trenching with multi-purpose machine. The swivel post is being used in the fully offset position to aid the operator's view of the work. (McConnel)

loader, by simply taking the pressure off the sprags, and pushing through the bucket and the main boom ram.

A considerable variety of attachments is available from some manufacturers. The most commonly used, in addition to ditching and trenching buckets, are grabs for manure or silage, root grabs for the loading of sugar beet, grabs with solid sides for fertilisers, grain, effluent, etc.

A high boom-pivot position is usually an advantage, making it easier to load high-sided vehicles and to reach over fences, etc. Now that agricultural tractors are fitted with enclosed safety cabs, it has become very desirable to have the operator's seat and controls within the cab. Arrangements are usually made to reverse the seat and to place the controls to one side.

An early tractor linkage-mounted type having a seat and controls which rotate with the boom resulted in some serious accidents through operators being trapped between the external rotating seat and rear members of the tractor safety cab. Carefully designed new models with more clearance, appropriate guards and sturdy hydraulically controlled stabiliser legs have overcome this operator safety hazard.

General-purpose light-industrial hydraulic excavators

A typical general-purpose hydraulic excavator (e.g. JCB, Massey-Ferguson, Case-International) is a much more complex and expensive machine, which is normally sold only as a complete loader/digger, and not as a tractor with attachments. Both a front-loader and a rear mounted digger are normally fitted, and it is unusual for either to be removed. The basic tractor is very similar to agricultural models, but usually has components designed to make it more suitable for the constant loading and digging work for which the machine is normally employed. The American Society of Agricultural Engineers, in conjunction with the Farm and Industrial Equipment Institute of the USA, has introduced standard methods of evaluating the capacity of various types of light-industrial equipment, particularly the two main items, the front-loader and the 'back-hoe', or slewing rear-loader/digger. Industrial machines have a longer reach and a larger bucket than the simpler tractor-mounted machines and require considerably more hydraulic power than is available from the standard tractor's normal hydraulic system. A powerful hydraulic pump is usually directly driven from the tractor engine. Offset operation is necessary for work along narrow ditches or alongside walls. Methods of achieving offset operation include sliding the king-post on which the jib pivots along an adjustment bar across the rear of the tractor, and on machines where the king-post is well to the rear, working with the tractor at an angle to the line of the ditch. With wider ditches, hydraulic back-acters can do effective work with the bucket moving across the ditch. There is no sharp distinction between light-industrial and farm equipment.

Machines with continuous cutting tools

Hydraulic loader/diggers have almost completely superseded machines with power-driven continuous cutting tools

for ditching work, though this type, with tools attached to a wheel or to an endless chain, is employed for trenching. For ditches where soft mud has to be removed there are foreign machines (e.g. Ritscher) with a high-speed shrouded Archimedean screw, but such machines require a specially modified tractor for operation, and their use is tending to diminish.

Trench-cutting machines

Back-acting trenchers

If a hydraulic digger is fitted with a suitable narrow bucket, it can do trenching work of a reasonable standard, provided that sufficient care is taken with finishing the work. The machine stands centrally along the line of the proposed drain and draws the scoop directly towards it, retreating from the work as the trench is completed. The excavated material is deposited at the side. A tooth at the bottom of the scoop can cut a groove for the pipes, to suit the size of drain required. The final touches are given with a 'bottoming' scoop. It is advisable to mark out the drain by drawing a shallow plough furrow before starting with the machine. Hydraulic diggers tend to be more suited to difficult jobs where there are rocks, and

specially deep work. They can work to a depth of about 2.7 m (9 ft) if necessary.

Rotary-wheel trenchers

Rotary-wheel trenchers with slow-moving cutters on the periphery have been successfully used in both tractor-mounted and self-propelled form in many countries for laying tiles or plastic pipe at depths up to about 1.5 m in reasonably stone-free soils. The soil removed is usually back-filled after introducing a porous-fill layer where necessary. Endless-chain/bucket types and trenchless pipelayers are now usually preferred by regular users.

A tractor-mounted shallow-depth slit trencher, having a pto-driven disc and peripheral cutters, is designed primarily for cutting narrow slits at depths up to about 35 cm for such purposes as treatment of small waterlogged depressions in growing crops. The soil removed can be deflected and widely scattered (e.g. Shelton STS). With maximum operating depth limited to about 40 cm, any need to obtain a continuous fall to a suitable drainage outlet can necessitate providing deeper trenching by some other means.

Endless-chain/bucket trenchers

A third main type of trench excavator employs an endless chain with buckets. Contractors' machines are usually self-propelled tracklayers with independent hydrostatic transmission and are made by specialist manufacturers in a range of power sizes. Features may include a pivoting digging unit to permit curved trenching; variable digging angle to suit soil conditions; adjustable track-width (narrow for transport, wide for work); an independent control cab carried on a height-adjustable boom; and a variety of attachments to facilitate all pipe-handling needs. A tracked, self-propelled gravel truck with adaptable delivery conveyors helps in minimising damage when draining through a growing cereal crop (Fig. 22.6).

This is now the main type of equipment for agricultural pipe drainage work, and the normal method of operation is to lay either clay tiles or polythene pipe in the bottom of the trench and cover the pipes with a permeable fill simultaneously. Large machines cut trenches up to over 3 m deep. The width of trench cut is often only about 150 mm (6 in) or a little less. When clay tiles are used these may be lifted on to the machine on pallets by



Fig. 22.5 195 kW tracklaying endless chain trencher with independent hydrostatic track drive. Standard features include oscillating tracks, plastic pipe reel assembly, liftable pipe box, and hydraulically supported independent cab. Options include laser depth control, conveyor to remove spoil, and gravel hopper. (*Mastenbroek 26-15*, one of a range of generally higher power and complexity for contract work.)



Fig. 22.6 Contractor's self-propelled gravel truck working in a growing crop in the same tracks as the medium-powered (145 hp) chain trencher-pipelayer, providing gravel fill and back-filling with staggered blades in a single bout to minimise crop damage (*Mastenbroek*)

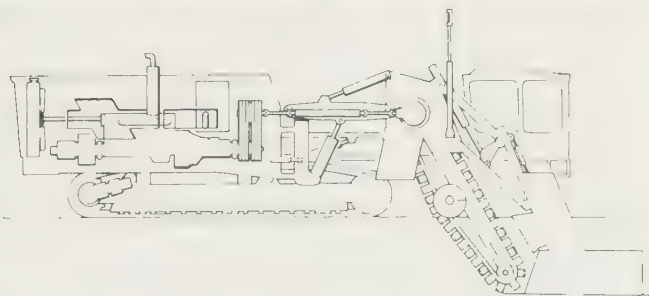


Fig. 22.7 A 172 hp bucket trencher laying plastic pipe has independent hydrostatic drive to oscillating tracks, and five-speed mechanical drive to pivoting digging unit with laser auto-grade system. Diagram shows general arrangement of main features, with the fully enclosed elevating cab at low level. (*Inter-Drain*)

means of a small crane carried by the machine. Polythene pipes are carried on large-diameter spools.

Many machines are designed for automatic depth-control by means of a laser beam. The laser system uses a receiver mounted on the drainer to detect a 'ceiling' of light energy which is emitted by a stationary transmitter or command post. The transmitter is set up at the far end of the field, and can project the ceiling over an area of about 24 ha (60 acres) from its rotating head. The ceiling can be at any desired angle, and is set before work begins by means of an extendable detector rod. The receiver on the machine detects the pre-set ceiling, and the signals are transferred to a control box which automatically adjusts the depth of work by control of the main grading ram. The equipment can be used on any type of trencher or trenchless pipelayer.

Tractor-mounted chain trenchers: A rugged chain trencher can be effectively mounted on the three-point linkage of a medium-powered tractor and moved forward by use of an infinitely-variable-speed drive applied through the tractor's external hydraulic system and its own drive wheels. The drive is applied by a pair of small-diameter cage wheels with a pattern of tread bars designed to engage the tread of the tractor's rear drive wheels. The cage wheels are pressed into contact by hydraulic ram, and driven by the tractor's external hydraulics. The digging chain is pto-operated via a torque limiter (e.g. AFT-65). A front-mounted back-fill blade provides a suitable balance to the normal trencher weight of about 900 kg at centre of gravity 53 cm behind the standard Category 2 linkage. Normal trenching speed is 150–300 metres/hour depending on depth. Choice of four boom lengths permits maximum depths from 0.85 to 1.30 m. The outfit reverts to normal drive via the tractor gearbox when the trencher is out of work (Fig. 22.8).

Trenchless drainage machines

Trenchless drainage machines open up a trench just wide enough to allow the pipe to be passed down a chute that follows just behind the bursting blade. The pull required to operate the machine in some soils at the maximum depth of 1.7 m ($5\frac{1}{2}$ ft) can be very high. A typical specialist machine has an engine of 250 hp with independent hydrostatic drive to tracks of the type used by industrial track-layers of this power. The trench-forming body, sometimes



Fig. 22.8 Tractor-mounted pto-driven endless-chain trencher with infinitely variable forward speed provided by a pair of small-diameter cage wheels, driven by the tractor's external hydraulics, and hydraulically pressed into engagement with the tractor's drive wheels during work. (AF Trenchers)

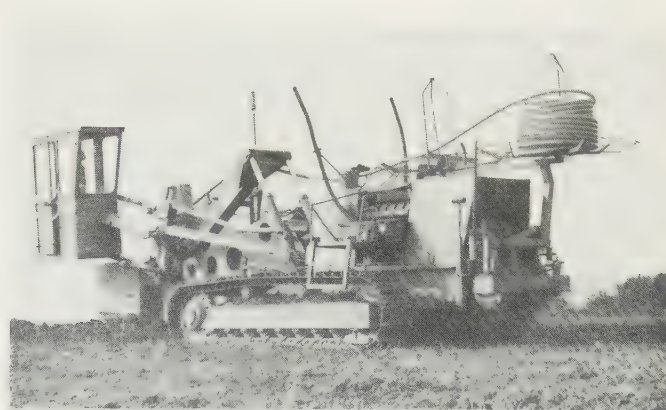


Fig. 22.9 Contractor's high-powered trenchless drainer laying plastic pipe. This machine, like other contractor pipelayers illustrated, is equipped with laser depth-control. The machine is equipped with elevating cab and gravel hopper. (Bruff TG 5-S)

After promising practical trials with a V-plough trencher, reduced demand for drainage equipment of all kinds by farmers and contractors was a factor in a decision by Mastenbroek to concentrate its efforts in the plough trencher field on its 2520 'Plow' of more conventional style than the 'V-Plow'. This 202 kW (275 hp) machine has a pivoting mounting of single leg parallelogram type, with gravel hopper incorporated; straightforward plastic pipe handling and the Company's normal well-proved standard and optional features for machines of this type, e.g. independent hydrostatic track drive, wide crew cab and oscillating tracks all standard (Fig. 22.10).

Gripping machines

Machines for cutting shallow U-shaped trenches may either consist of a simple drainage plough, or may employ pto-driven rotary cutters to cut the spoil and spread it. This form of surface drainage can be useful on marshland subject to occasional flooding, and in other situations where an underground system is impracticable or not economically justified. A typical three-point linkage mounted machine has an inclined milling wheel with a series of cutting blades, driven at 270 rpm. The spoil can be spread over a strip up to 12 m (40 ft) wide if required. Maximum working depth of most gripping machines is no more than 0.5 m. For useful work on boundary ditch maintenance, minimum requirements are an offset beyond

called a 'plow' is designed to cut and lift soil. It has a curved blade with a following hopper and long narrow chute for putting permeable fill over the pipe. Plastic pipe is generally used but clay tiles up to 150 mm (6 in) diameter can be laid. The soil surface tends to be left in a very ridged condition. If it is necessary to draw moles across the work very soon after the pipes are installed, research by Silsoe College shows that it is essential to press down the loose soil above the pipes before mowing to avoid early mole collapse. This is best done by running a heavy tractor or machine down both sides of the pipe as soon as possible after the main pipes are laid.



Fig. 22.10 Plough trencher equipped for laying plastic drainage pipe with gravel fill. The V-10 air-cooled diesel 275 hp engine employs independent hydrostatic drive to oscillating tracks. Single leg parallelogram mounting and laser depth control. (*Mastenbroek 25-20 Plow*)

the tractor wheel of about 1.5 m and ability to work 1 m below ground level.

Mole drainage

Mole drainage consists essentially of drawing a bullet-shaped steel mole or cartridge through the subsoil. It is practicable only on very heavy land in a moist condition. The process has been employed for over 150 years.

The important principles of drainage in heavy or clay soil have been shown to be broadly as follows: (a) heavy soils on which, alone, mole draining can be successfully performed, are almost impermeable to water in the undisturbed lower layers during the drainage season; (b) drainage from these soils is essentially surface drainage and takes place by the passage of water through major inter-spaces in the soil rather than by percolation through it. The permeability of such soils may be improved by suitable cropping and tillages; deep cultivations when the soil is dry assist materially in the drainage of such land.

It is possible to carry out mole draining at a comparatively low cost on heavy soils where there is a natural fall, and where the subsoil is uniform undisturbed clay. A fall of 1:500 may be sufficient for short lengths of mole, but it is desirable to have more where possible, and good results cannot be expected with falls of less than 1:200. The surface of the ground needs to be free from irregularities of contour, and best results can only be obtained if the subsoil is free from pockets of sand, gravel or pebbles.

Moles range in diameter from 50–100 mm (2 to 4 in), and are usually pulled through the ground at a depth of from 300–600 mm (12 to 24 in). The mole cartridge and an expander 13 mm ($\frac{1}{2}$ in) diameter larger squeeze the plastic clay outwards and leave a channel which forms the drain. Well-constructed moles have been said to function for 50 years, but the normal life is from 5 to 15 years. Factors making for success are careful planning of the system and the construction of suitable tiled main collecting drains, with a good depth of permeable fill above the tiles, and well-protected outfalls. If the mains are well constructed the life of a system may be indefinitely prolonged by redrawing the mole channels at intervals of



Fig. 22.11 A three-point-linkage-attached beam type mole plough with variable-pitch headstock to provide quick entry; earth-levelling skids at the front to remove clods or smooth out back-fill ridges; and three pairs of steel wheels (with scrapers) to reduce draught and secure uniform working depth. Blade pitch adjustment is incorporated; ceramic expander optional. Usual power requirement is from 70 hp. (*Michael Moore*)

a few years. The moles are usually drawn from 1.8–5.4 m (2 to 6 yd) apart, but where the land is laid up in ridge and furrow they should run along the furrow bottoms. Their length should not exceed about 0.2 km ($\frac{1}{8}$ mile), and there should be a gradual fall throughout the length.

Methods of mole draining

Powerful tracklaying tractors can do good work by direct haulage of the mole plough, and if the conditions are such that the tractor can secure good adhesion, even a medium-powered wheeled tractor can usually pull a small mole about 450 mm (18 in) deep. Pulls of 22–44 kN (5000–10 000 lbf) are required to pull 75–100 mm (3–4 in) moles 500–600 mm (20–24 in) deep.

Drainage should be performed when the subsoil is moist, for the draught is much lower in wet soils than in dry. Moreover, the drains are more likely to last well if the soil is moist and plastic enough to leave the walls of the mole smooth. But in deciding on the best time to operate, other considerations are involved. The surface must be dry enough to carry the tractor, for the high drawbar pulls necessitate a good grip by the wheels or tracks. The right conditions of surface soil and subsoil most frequently coincide in the spring, when the surface has dried out and the subsoil is still wet. The early winter is also sometimes favourable.

Mole drains work best in the first five years of their life, and it is gradually becoming recognised that drainage of heavy land should be regarded more as a cultivation than as a permanent improvement.

Experiments on Lower Lias clay indicate that the best and most economic results are achieved by close spacing of moles (about 2 m) over tile drains. Spacing of the tiles between 15 and 60 m was comparatively unimportant. In wet seasons differences in yield of winter wheat could be up to 1 tonne/ha.

Mole ploughs

A type of implement favoured where mole drainage is regularly practised has a long (3.7 m) floating beam with skids at front and rear, a pneumatic-tyred carriage and hydraulic (or winch) lift. This type, with 76 mm (3 in) mole, capable of working to about 0.8 m depth, requires a tractor of 80 to 100 hp to power it effectively, and is

often contractor operated. Experiments have shown that draught can be substantially reduced by substituting wheels for skids.

Tractor-mounted mole drainers

Mole drainers suitable for mounting on the hydraulic three-link system have been developed for use with medium-powered tractors. The action of these simple mounted drainers can be satisfactory in most conditions, the three-link hitch permitting the implement to float smoothly even if the tractor passes over rough ground.

The mole plough is attached by links which converge in the vertical plane, and it behaves as if it were being pulled from the virtual hitch point, which lies in the region of the tractor's front axle.

Medium-powered tracklayers can also be equipped with a hydraulically operated tool-bar capable of carrying a mole, or in some cases two.

It is impossible for the cartridge of any mole plough to start work at the full depth of the mole channel without either digging eye-holes or starting in the ditch. The best practice is to start in or as near to the ditch as possible with an implement which automatically draws itself into the soil and attains its full depth before passing through the porous layer above the tiled main drain.

Jetters for drain cleaning

Jetters for cleaning of tile drains can be useful for maintenance of performance in difficult soils, e.g. silts and some unstable sands, if used when deposits are still moist, in early spring. A unit of advanced design (e.g. Mastenbroek) is three-point-linkage-mounted and has a transversely mounted reel carrying up to 400 m of plastic hose. A pto-driven double diaphragm pump delivers 60 litres/min at 40 bar when driven at 500 rpm. The unit is positioned above or opposite the drain outlet and, after inserting the nozzle in the outlet, the operator works from the tractor cab. The cleaning nozzle is propelled up and down the pipe by a push–pull head with multiple forward and rear-facing nozzles. The forward jets loosen the sediment and the rear jets provide propulsion to complete the cleaning. The reel is mechanically rewound without the operator needing to leave the cab. An arm carrying float and filter is folded for road transport.

Machinery for land reclamation

The best method to employ for clearing scrub depends on the size and density of the bushes. For isolated bushes or trees there is probably nothing better than pulling them out with a wire rope, power being supplied by a hand-operated monkey winch, or a tractor with or without a winch attached, according to the equipment available and the number and size of the bushes to be dealt with. Most bush clearing must be done with the ordinary farm tractor, but where the bushes are more numerous than about 500 per acre, the cost of pulling them individually is prohibitive.

'Bulldozers' have frequently been used with success for bush and hedge clearing, but they often take too much soil with the bushes and so make burning difficult.

Various kinds of tractor-mounted bush digger, pusher and sweep have also been built and used successfully by both farmers and contractors.

Other useful tools include stumpers and root rakes. These are usually designed for mounting on a hydraulic bulldozer frame, and in the hands of a skilful operator they can push out trees and bushes with a minimum of soil adhering to the roots.

Bulldozers, angle-dozers and graders

The equipping of most medium-powered British tractors with hydraulic lift systems has facilitated the development of simple earth-moving devices which are of great value for many purposes.

The term 'bulldozer' is applied to a blade set square across the front of the tractor, while 'angle-dozer' refers to a blade set at an angle. The same blade and equipment can often be used for both purposes, by using different methods of attachment between the blade and the framework connecting it to the tractor.

Both bulldozers and angle-dozers are usually more effective on tracklayers than on wheeled tractors, but provided that a medium-powered wheeled tractor equipped with a dozing blade is intelligently used it can do a great deal of useful work on such jobs as removing unwanted banks and hedges, filling in drainage trenches, etc. A tracklayer or four-wheel-drive unit can do slightly heavier work than a conventional wheeled tractor, on account of its extra push.

None of the earth-moving devices mentioned above



Fig. 22.12 Dozer blade seen on basic tractor (without safety cab). The blade angles 25° either way, tilts 5° , 10° or 15° , and offsets to either side when angled. (Bomford)

are really suitable for accurate levelling, or for the final shaping of road surfaces. For this purpose a grader or leveller with a fairly wide and easily adjustable blade is required. The grader blade consists of a curved body with a hard steel cutting-edge. Graders suitable for use



Fig. 22.13 General-purpose grader/scrapper with easy adjustment of blade angle, blade tilt and beam offset demonstrates its versatility. (Bomford)

on the three-link system of British tractors are available and can do good work. When grading a road, the leading end of the blade is run at the road side, and this is set lower than the trailing end by means of the levelling screw on the hydraulic linkage. This causes earth to be excavated from the side and pushed up to the crown, the same setting being used on the return journey to deal with the other side of the road. The employment of the usual type of three-point linkage system, giving a virtual hitch point near the tractor's front axle, ensures that the blade works at a reasonably constant level.

Tractor winches

For work where very heavy pulls are needed, such as pulling trees, etc., it is often desirable to be able to increase considerably the maximum pull of a tractor by fitting a winch.

Winches vary considerably according to whether they are a subsidiary or a major feature of the tractor concerned. Some light winches can be used without interfering with the operation of the tractor's hydraulic lift system. On the other hand, some winches for tree-pulling, etc., equipped with anchors and other refinements, almost hide the tractors around which they are built.

Whatever type of winch is used, it is essential, for satisfactory service, that the gears should be of high quality, and that the winding drum should be so designed and constructed that the cable winds on reasonably uniformly.

Owing to the very high pulls which it can exert, a winch can be extremely dangerous if not correctly operated. It must always be remembered that if the winch rope is connected to an immovable object, it is the tractor that will move, and the only way in which it can move if the anchor holds is by overturning. The tractor must generally be set exactly parallel to the line of pull, and the operator must quickly disengage the drive if the resistance is too great.

Stone clearance equipment

Stone windrowing techniques concerned mainly with avoiding stone troubles when growing potatoes or some other root crops are discussed in Chapter 7. There are conditions on some light soils where a more permanent



Fig. 22.14 Stone and rock clearing machines. Stone separator with side-loading elevator used for contract work. (*Reekie*)



Fig. 22.15 Pto-driven semi-mounted stone rake (left) forming windrows which are picked and loaded by the pto-driven semi-mounted stone picker. (*Kverneland*)

improvement can be worth consideration. Equipment developed primarily for severe Scandinavian conditions includes a stone rake and a stone picker which are complementary but can also be used independently. The semi-mounted rake available in widths of 2, 3 or 4 m has a pto-driven tined rotor which is inclined to the direction of travel and rotates slowly against the direction of travel at a normal working depth of about 10 cm (4 in). It delivers the larger stones in a windrow which can be gathered and loaded by a stone picker. The picker, with working width 1.65 m can work direct or lift a windrow. It is semi-mounted, pto-driven and lifts by a share on to a bar riddle which is swept by a chain conveyor up an inclined vibrating elevator with a bed of 6 or 7 bars to

match those of the horizontal riddle. The bars are attached to the frame by springs which provide individual vibration and freedom from blockage. An alternative loading method suited to large stones is by a stone fork operated by a tractor or rough-terrain loading vehicle.

Bracken-cutting and scrub-clearing machines

Where land can be ploughed, bracken eradication is most easily and reliably accomplished by ploughing and thorough cultivations. This method is not, however, applicable to most of the hill land that is in need of improvement, and various types of bracken-cutting and bruising machines have been developed for this purpose.

One of the most useful machines for bracken clearing, as well as for clearing many other types of light scrub, is a pto-driven rotary slasher, with hinged horizontal bars or chains which are driven at a fairly high speed beneath a metal cover. Some rotary slashers, developed since position-control became available on tractors, have the slasher mounted on the three-point linkage and adjusted by position-control, in conjunction with a trailing wheel. Other machines that can do good work in clearing light scrub include sturdily built flail-type pulverisers.

It is essential for success to deal with bracken at the height of the season. The work must be done before the bracken is too old, and must be repeated when new growth appears, and also in subsequent years. Extensive trials carried out over several years in Scotland indicate that machines which cut the bracken are rather more effective than those which only bruise it. Cutting machines should, therefore, be chosen for use on those sites where they can be effectively operated.

Hedge and verge trimmers

One of the most generally useful types of flail hedge and verge trimmers is designed for mounting on a general-purpose tractor, preferably four-wheel-drive, with engine of about 65 hp and Category 2 three-point linkage. The trimmer normally has a flail head 1.2 m (48 in) long and is equipped with a pto driven self-contained hydraulic unit to provide the drive to the flail head. A modern machine having maximum reach (with head horizontal) of 4.58 m (15 ft) and height with head vertical of 4.92 m



Fig. 22.16 All-hydraulic flail hedge or verge trimmer attached by standard Cat II three-point linkage, tackling overgrown scrub which has been neglected too long to be ideally suited for treatment by a machine of this type. (Bomford B48 XL)

(16 ft) can be used at either side of the tractor, has an angle of head movement of 244° , and uses in-cab electric control of all arm movements (e.g. Fig. 22.17). An important feature of the head regulation called 'Auto Head Control' maintains the exact angle at which the flail head is initially set when alterations are made by the driver to either height or reach. This is achieved by a unique combination of parallel arm geometry and two small hydraulic compensator rams. The system is normally used to keep the cutter head parallel to the face being cut; and it enables cutting work to continue at its pre-set angle immediately after any height or reach adjustment has been made.

Long-reach power-arm flails

A recently developed series of long-reach and heavy-duty flails (McConnel PA 2000 Series) is designed primarily for the use of professional contractors or other users of heavy equipment and is based on attachment to the 70 hp



Fig. 22.17 Latest in a successful line of hedge and verge cutters mounted on standard three-point linkage of general-purpose tractors of at least 48 kW (64 hp). The pto drives the hedger's independent hydraulics system: all hedger controls are electro-hydraulic and easy to reach by the tractor driver. The modern design locates the 1.2 m (4 ft) flail head slightly forward, where the driver can easily see normal hedging work. The proven parallel arm linkage geometry maintains flail height almost irrespective of reach, and a new 'auto head' control fitted as standard minimises the need to change head angle when height or reach are varied (RASE Silver Medal 1990). (McConnel PA95)

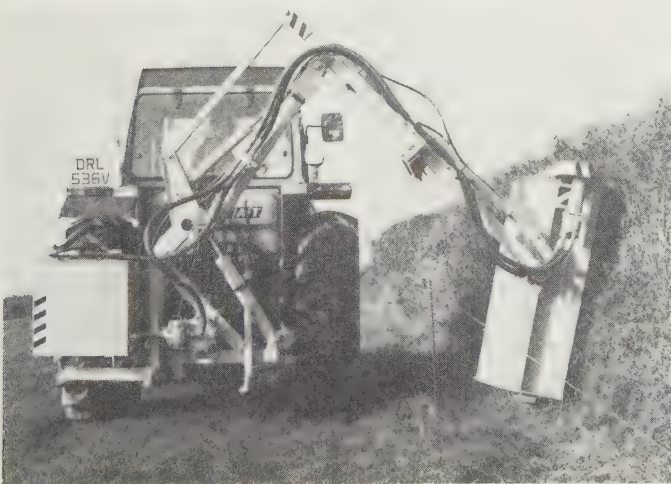


Fig. 22.18 A three-point-linkage-attached hydraulically powered flail hedge cutter, with pto-driven pump for rotor drive, has hydraulic oil tank arranged to help to balance rotor weight; parallel linkage facilitates position control. (Teagle)



Fig. 22.19 Heavy-duty medium reach flail hedge/verge trimmer rigidly attached to tractor axle by new latch system illustrated in Fig. 22.20. The photograph shows the forward position of the flail head during work. (McConnel PA 2080)

tractor by a patented 'Latch-on' rigid mounting mechanism to provide adequate resistance to the twisting effects of very long or complex booms. Figure 22.19 illustrates a typical example, the PA 2080, which has the boom mounted at the front end of a forward extension from the parallel linkage and neatly positions the flail head on a sideways reach line to the flail head slightly forward of the tractor driver when at the centre point of the 97° power slew angle. This provides a good location for the driver to avoid immovable obstacles or to work round trees or bushes. The heavier machine construction justifies use of the 'Latch-on' system which could provide a sound basis for development of an international standard to suit heavy mounted equipment of many kinds. Figure 22.20 illustrates some features of the Latch-on mounting system.

Rotary cutters

Tractor-mounted rotary saw cutters are capable of dealing with overgrown and neglected hedges, and reducing them to reasonable proportions. These are usually contractors' machines. The revolving blades can be adjusted to cut at various heights and angles. Some machines can be set to cut the far side of a hedge. Guards are provided to protect the operators from flying pieces of wood, and it is essential that these be used and that due regard is paid to the somewhat dangerous nature of the cutting mechanism.

Both drive to the cutting mechanism and control of the height and angle of cut are hydraulically operated on most modern machines. On others, the drive is by pto

and belting, but control of height and angle are effected by hydraulic cylinders. As a general rule, the tractor's standard hydraulic system is adequate for the controls, but where a hydraulic drive is required a supplementary hydraulic pump is usually needed. A slasher blade is suitable for trimming, but a saw blade is needed for heavy growth.

Operation of flail trimmers

Flail-type trimmers have rapidly come into general use in spite of a fairly high capital cost, mainly because there is no clearing-up problem when they are used on light to medium growth. They have the great advantage of being able to deal with brambles, and of being capable of cleaning up dyke banks. They can easily deal with hedge growth of about 25 mm (1 in) thick, but give best service if used for regular maintenance. The work done on lighter growth has not quite as good an appearance as that done by a cutter-bar machine, but is generally satisfactory. The flail mechanism is usually hydraulically driven, and this requires use of a pto-driven hydraulic pump, with an output of about 63 l/min at 172 bar (14 gal/min at 2500 psi). The hydraulic adjustments are usually carried out by use of the tractor's normal external hydraulic services.

One type of flail rotor has the flails so attached that they can rotate on the axis of the fixing pin through 360°, so being able to withdraw within the diameter of the rotor when an obstruction is encountered.

When used for light trimming, leafy material may be blown flat by wind created by the rotor. In such conditions a low rotor speed is often best. When strong growth has to be cut (diameter over 50 mm) it is advisable to make a number of short cuts in succession, taking no more than 400 mm at each pass. If thick branches up to 100 mm have to be cut by flail, each has to be tackled in turn, with the rotor being slowly moved down from the top to the desired height. Heavy growths are best dealt with by a circular saw type.

Post-hole diggers

Power-driven post-hole diggers which are now available for attachment to the hydraulic power lift of most British tractors save a great deal of time where many holes are

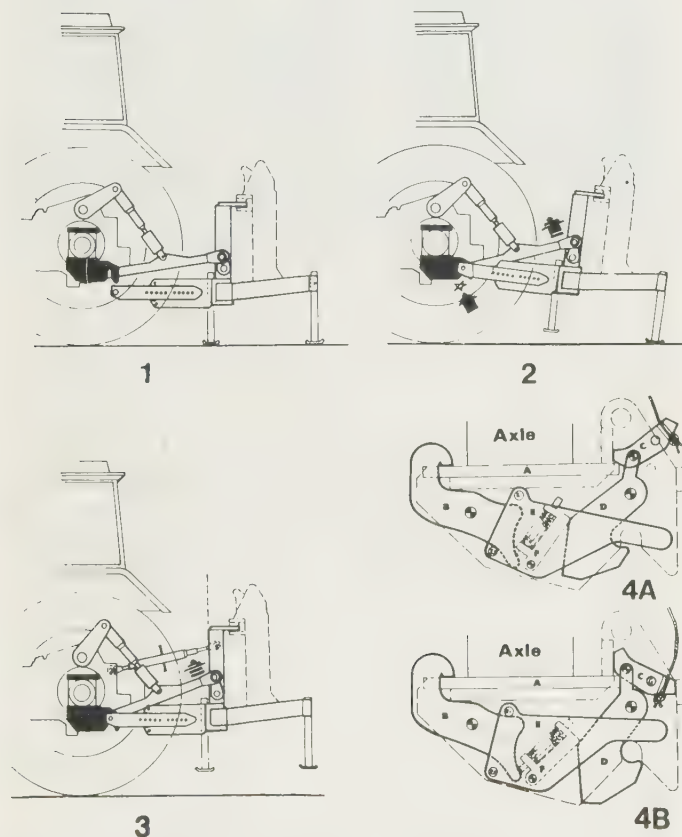


Fig. 22.20 Rigid latch-on system for fitting McConnell heavy-duty long-reach 2000 Series flail hedge and verge trimmers to tractor rear axles.

1 Special axle brackets (shown heavy black) are bolted to the tractor's rear axle 1 or 1.1 m apart. These remain on the tractor. Tractor reverses to parked flail machine and the standard lower draught links are pinned into the machine.

2 The flail is lifted by the lower links until the spring loaded latch on the mounting catches attached to the tractor axle brackets (**4A**) snap on to the machine's adjustable reaction arms. The catches are then locked by pins (**4B**).

3 Lifting the machine is resumed until the machine frame is vertical: the top link and pto shaft are connected. The leg stands are stowed and the flail is ready for use. To detach, the locking pins are removed, an in-cab release cord is pulled and the flail is lowered on to its leg stands. (Latch system by *Tractor Fittings Ltd*)

required. The digger consists of an auger which is driven through bevel gears by the tractor power-take-off. Auger points and the leading blades are made replaceable, and different shapes of point are available for dealing with different types of soil. With a typical machine, auger speed is about 80 rpm and it takes about $\frac{1}{2}$ min to dig an average-size hole. Working depth is 0.9–1.5 m (3–5 ft) and auger diameter 0.15–0.6 m (6–24 in). Adjustment is provided to allow vertical holes to be drilled on sloping land.

Post drivers

There are two main methods of using tractor power to assist in driving fencing posts into the soil. One method is to raise a weight and drop it, as in a typical pile driver. The second method is to use a linkage system to press the post into the soil by means of the tractor's weight.

The Parmiter, a three-point linkage device, employs the tractor's external hydraulics to operate a ram which, by leverage and chains, raises the weight up to 2.4 m (8 ft) high. The post is gripped by a clamp on the three-point linkage model, which also provides adjustments for getting the posts driven in vertically.

The pole press is a device attached to the three-point linkage of a tractor which makes direct use of the hydraulic lift linkage and the tractor's weight to force the stake into the ground. When the tractor's lower links are raised, they pull on wire ropes which pass round pulleys and force downwards a steel cap fitted over the top of the post.

Road sweepers and slurry scrapers

Tractor-mounted road sweepers are designed primarily for use on highways, but can in some circumstances be usefully employed for cleaning large areas of concrete on farms. A common type has a cylindrical brush mounted at an angle to the direction of travel. Front-mounted brushes are available, but a type more easily attached to the tractor is mounted on the three-point linkage.

Such pto-driven sweepers are considerably more expensive than simple slurry-scrapers, and no more effective



Fig. 22.21 Offset tractor-mounted post-hole digger. (Econ-Lister)

for dealing with slurry. An essential feature of the design of a good slurry-scraper is a reasonable amount of transverse flexibility, and side wings to prevent the slurry spreading sideways. It is an advantage to have wings at both front and rear, or capable of being easily adjusted in either direction. The wings should be flexibly attached, so that they can follow uneven ground contours effectively.

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Environment Control in Crop and Stock Buildings

Introduction

Control of environment in agriculture and horticulture consists mainly of regulating heating, cooling, ventilation, light and moisture. Control of ventilation may involve the proportions of the main gases of the store atmosphere, viz. nitrogen, oxygen and carbon dioxide, as well as its moisture content. The main buildings involved are commercial greenhouses, potato stores and chitting houses, vegetable and fruit stores and buildings for livestock housing. Construction of the buildings themselves is obviously important, but the only aspects considered here are those directly concerned with environment control. Similarly, important husbandry aspects are only briefly mentioned to explain the main objectives of control systems. Systems range in cost and complexity from cheap means of assisting and regulating natural ventilation to computer control of heating, ventilation, watering, carbon dioxide and light for optimum large-scale glasshouse crop production. Basic heat exchange calculations apply to all environment control systems and are therefore dealt with first. Some readers may, however, prefer to study applications first and to return to calculations after the survey of needs and equipment to which this chapter is chiefly devoted.

Calculation of heat gains/losses

Heat flows to or from an enclosed environment in one or more of three ways: by conduction through the structure; by ventilation and air exchange; and by radiation.

Conduction

The total heat flow depends on the insulating properties of the components of the structure (U value), their area,

and the temperature difference between inside and outside. The heat flow through any component (wall, roof, floor etc.) is given by:

$$Q_s = UA (t_i - t_o)$$

where Q_s = heat flow (watts)

U = U value of the structure ($\text{W/m}^2\text{°C}$)

A = the area of the component (m^2)

t_i and t_o are the inside and outside temperatures (°C)

The total heat loss/gain is found by adding the values of Q_s for all the parts of the structure. A list of typical U values is given in Table A6.2.

Ventilation

Heat loss or gain due to ventilation depends on the ventilation rate (m^3/s), and the temperature difference. It may also be affected by moisture loss or gain by the ventilating air and by the degree of mixing occurring between inlet and outlet. Where there are no moisture changes the heat flow Q_v is given by:

$$Q_v = Vpc (t_i - t_o)$$

Where Q_v = heat flow (watts)

p = density of air (typically 1.2 kg/m^3)

c = specific heat of air (typically 1008 J/kg°C)

V = ventilation rate, m^3/s

t_i and t_o are inlet and outlet temperatures respectively °C

Where there is a significant change in the moisture content, the term $c(t_i - t_o)$ should be replaced by $(e_i - e_o)$ where e is the enthalpy (J/kg) of the inlet and exhaust air. These values may be found from psychrometric charts or tables.

If the ventilation rate is known in terms of air changes per hour, the equation becomes:

$$Q_v = 0.336 \, BC \, (t_i - t_o)$$

where B = the building volume m^3
 C = the air changes per hour

Radiation

Conduction heat gains and losses may be affected by radiation from or to the external surface of the building. Solar gains may be important when determining the refrigeration or ventilation requirements under summer conditions, while radiation frosts may result in unexpected condensation or additional heating requirements in winter.

Environmental control in commercial greenhouses

Use of greenhouses allows a much larger measure of control to be exercised over the aerial and soil environment of crop plants than in outside culture. The important factors over which control is exercised are air temperature (and to a limited extent, soil temperature), humidity, carbon dioxide concentration, and sometimes light.

Precise control of temperature in glasshouses is a more difficult problem than in industrial buildings. The structure itself is designed to provide maximum light transmission. The result is a building which has a very high thermal transmission coefficient and a low thermal mass. These factors combine to produce a load which varies rapidly from heating to cooling, and vice versa, with changes in ambient conditions.

The heating and cooling equipment must be designed to maintain the required temperature under the normal worst conditions. These only occur unpredictably and for a short period each year. Thus, the equipment only operates at design capacity for a small part of its life.

Plant temperature is an important factor affecting growth and development but because this is difficult to measure, true air temperature is used in defining requirements. As growth is related to temperature, the latter must be as uniform as possible throughout the growing zone to provide an even crop.

The heating system in a glasshouse should have low capital and running costs, the latter being often the more important.

Commercial greenhouses in the UK are heated by automatically fired boilers, a situation dictated not only by labour cost considerations, but also by the increasing accuracy of temperature control demanded by growers.

Oil fuel is more widely used than coal, mainly because it is more easily handled by fully automatic firing equipment. However, spiralling oil prices can result in significant swings to coal firing.

Oil fuels fall into a number of categories designated by the maximum viscosity. Table 23.1 shows the main properties of the most widely used grades. Oil fuel suppliers have their own names for grades, but the viscosity is always stated.

In general, the cost per litre decreases with increasing viscosity, and this, together with the higher calorific value, makes heavy oil a cheaper source of heat than light oil. This is offset to some extent by the fact that the capital and running costs of firing equipment for heavier oils are greater than those for the lighter grades. Pre-heating of heavy grades is necessary to reduce the viscosity to a value at which the oil can be easily burned. Large boiler installations tend to burn heavy grades of oil, while small ones (up to 300 kW) burn gas oil.

Storage should be provided for at least three weeks' running at maximum heat demand. This should be ample to tide over a period of bad weather which might interrupt supplies. Deliveries are usually in loads of 9000–24 000 l by road tanker.

Table 23.1 Typical characteristics of fuel oils

<i>BS 2869:1970 Grade</i>	<i>D</i>	<i>E</i>	<i>F</i>	<i>G</i>
Viscosity (Redwood No. 1 @ 37.8°C)	35	250 max.		
Kinematic				
Viscosity cSt @ 37.8°C	3	—		
@ 82.2°C	—	12.5	30	70
Gross calorific value				
kJ/kg (approx.)	45 590	43 500	43 030	42 800
kWh/l (approx.)	10.57	11.22	11.22	11.42
Ash content % wt	—	0.02	0.03	0.04
Sulphur content % wt	0.6	2.3	2.4	2.5
Max sulphur content to BS 2869:1970% wt	1	3.5	4.0	4.5

Storage tanks may be rectangular, horizontal cylindrical or vertical cylindrical, the actual type depending on the size and storage capacity required. It is important that no galvanised fittings be used in connection with oil-handling installations. Heavy oils require a heater so that the oil may flow easily to the outlet, and an outflow heater which further heats the oil as it passes from the tank. In addition, the pipelines to the burners must be lagged to maintain the oil temperature and are usually 'traced' with thermostatically controlled electrical heating tape to enable the heating plant to start up from cold.

Oil firing equipment

For efficient combustion the oil and air must be intimately mixed. This is achieved by atomising the oil, and the commonly used types of burner are designated by the method used to achieve atomisation. Not all burners will burn all grades of oil correctly. Burner control may be by (a) on/off action, which is common on very small boilers; (b) high/low/off control; and (c) fully modulating/off. The latter two types are more expensive than on/off but they enable better thermal efficiencies to be obtained, since input can be more closely matched to output, and also reduce the thermal shock loadings on boilers.

Pressure-jet burners are the most common type on nurseries. They are usually limited to oil of Grades D, E and F, although oil of Grade G can be handled by some models. The oil is pumped at a pressure of 7–14 bar through a nozzle, emerging as a fine spray into the stream of combustion air provided by the fan (Fig. 23.1). Ignition is by high-tension electric spark from two electrodes situated close to the nozzle.

Air-atomising burners. Atomisation in this burner takes place when oil is sprayed from a low pressure nozzle into a high-velocity air-stream. An advantage is that the nozzle diameter is larger than in the pressure jet, thus making blockages less likely. Two versions of this burner are used on nurseries — one uses low-pressure atomising air at 0.01 to 0.07 bar from a fan, and the other uses medium-pressure atomising air at 0.2 to 1.0 bar from a compressor. The latter type is more widely used, but neither is as common as the less sophisticated pressure-jet type or the rotary-cup type.

Rotary-cup burners. In this burner (Fig. 23.2) oil is pumped at low pressure to the centre of a cup rotating at high speed. The oil forms a thin film on the inner surface of the cup, and as it reaches the edge it is thrown off in a large number of small droplets. Primary air supplied by a fan integral with the cup is forced through the droplets to complete the atomisation. Ignition is usually by high tension spark igniting a gas flame which in turn ignites the oil. This type of burner is less sensitive than other types to the condition of the oil reaching it, since atomisation does not depend on the use of a fine nozzle.

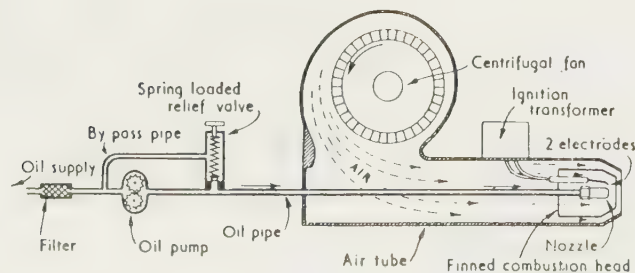


Fig. 23.1 Pressure-jet burner layout.

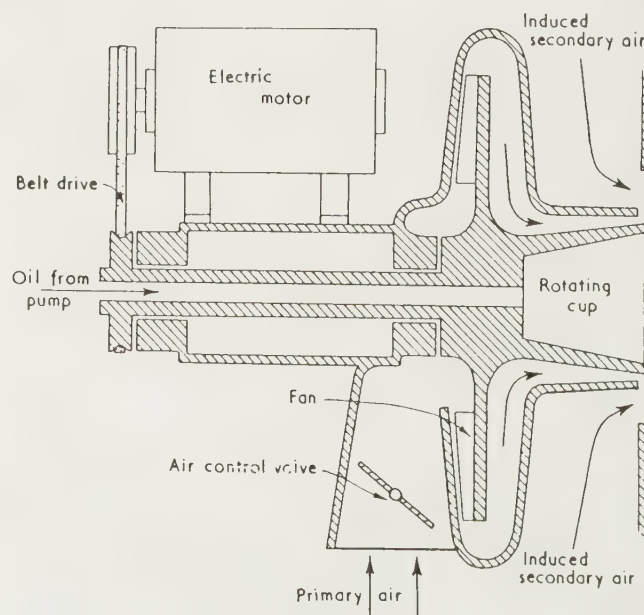


Fig. 23.2 Rotary-cup burner layout.

Solid fuel firing equipment

Automatic firing equipment requires a supply of carefully graded fuel of consistent quality. The calorific value of bituminous coal generally ranges from 26.7 to 29 GJ/t. The value for anthracite is about 32.5 GJ/t but use of this fuel is limited to boilers of about 300 kW or less because of its higher cost.

Underfeed stokers are the most common fully automatic type and they can be fitted to a wide range of boilers from about 50 to 2000 kW (Fig. 23.3). Fuel is fed from a hopper or bunker situated at the back, side or front of the boiler to a worm or ram which gradually conveys it along a tube to the bottom of a retort inside the boiler. Air from a fan driven by the same motor as the fuel feed mechanism is delivered to the retort through ducting. Both the air and fuel supply are automatically controlled. As the fuel rises in the retort, volatile materials are driven off and are burned as they pass through the incandescent mass of the fire. The ash is pushed over the side of the retort and is usually removed by hand at regular intervals. However, an automatic de-ashing system has been developed.

Washed bituminous singles coal suits this type of stoker well. If abrasive fuel is used, excessive wear may take place unless the stoker has been specially designed to handle such fuels.

Chain-grate stokers. A chain consisting of cast iron links runs horizontally beneath a hopper, conveying the fuel into the boiler furnace. The depth of fuel on the chain is controlled by a movable gate, and the speed of the chain is variable. On entering the furnace the fuel passes under

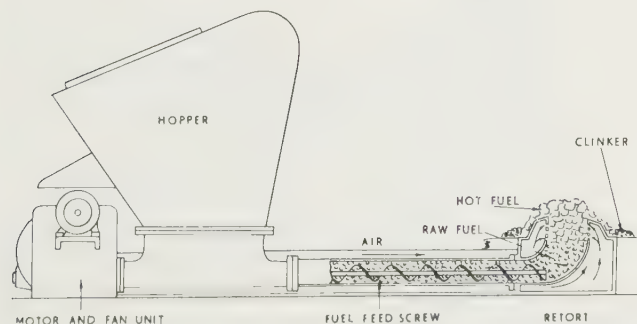


Fig. 23.3 Hopper-type underfeed stoker.

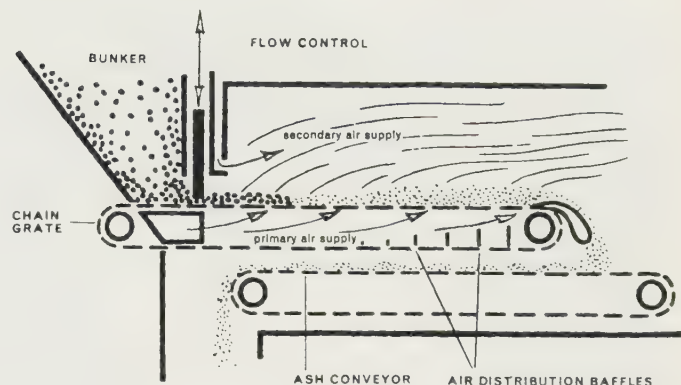


Fig. 23.4 Chain-grate stoker with ash-return conveyor. (National Coal Board)

a hot firebrick arch, radiation from which releases the volatiles and assists ignition. Ash and clinker are tipped off the end of the chain into a pit or receptacle, depending on the type of boiler to which the stoker is fitted. Some stokers have a second chain moving beneath the first in the opposite direction to provide automatic ash-removal at the front of the boiler.

One advantage of the chain-grate stoker is that it can handle small coal which is cheap to buy. Fuel with a high ash content or which is strongly caking should be avoided.

Coking or low ram stokers have a moving grate with longitudinal firebars driven forward by cams or hydraulic rams and subsequently pulled back in groups of alternate bars. The fuel and ash are steadily carried forward, and ash passes over the end into a disposal system. This type can burn a wide range of coal but works best on washed bituminous singles.

Top- or front-fed firing systems are a development of solid fuel firing for shell-type boilers in which fuel is pneumatically fed on to a fixed grate in the furnace tube. Air is forced in both through the grate and above the fire. The front-fed is designed for converting boilers from oil to coal firing as well as for new boilers.

Natural gas firing

Natural gas is about 90% methane and has the advantages of cleanliness, no storage need, low chimney height, good

source of CO_2 for atmosphere enrichment, and paid for after use at a competitive price. Calorific value is about 39 MJ/m^3 . The gas may be burned in conventional small boilers of natural draught type which are almost silent; the compressor needed for larger sizes can be noisy. The problem of distance from mains prevents widespread adoption.

Straw has been used as a fuel but has not yet become a major competitor for coal, oil and gas.

Problems with using straw include:

- Storage: bulk density is low
- Automatic firing is costly

Advantages:

- Home produced
- Low cost if available locally

Boilers

Boilers may produce steam at pressures not usually above 8 bar or hot water which is discharged from the boiler at temperatures from 77° to 88°C (unpressurised) to 127°C (medium pressure).

The efficiency with which a boiler transfers heat (thermal efficiency) depends on a number of factors, both technical and managerial. One important factor is the quantity of air supplied to the furnace. Where this greatly exceeds the amount required for complete combustion, heat is wasted in raising the temperature of this excess air. Therefore the air supply should be accurately controlled. The best indication of whether the correct quantity of air is being supplied is the concentration of carbon dioxide (CO_2) in the flue gas. Suitable equipment for the measurement of CO_2 in flue gases may vary from a simple portable apparatus to the more costly automatic recording equipment permanently installed in large boiler houses.

The temperature of the flue gases gives an indication of boiler thermal efficiency. The minimum practicable flue gas temperature is about 200°C but actual values depend on the type of boiler and the degree to which it is 'forced'.

Other heat losses from boilers occur by radiation from the external surface and by conduction into the floor in the case of non-shell-type boilers. Modern packaged boilers are well lagged to reduce these losses to a minimum.

Many types of boiler are in use for glasshouse heating, and only the main types are dealt with here.

Sectional boilers are constructed in sections bolted together and provided with communicating waterways. The sections may be of cast iron or mild steel. The advantages of a sectional construction are (i) cast iron may be used and is less susceptible to acid corrosion than steel, (ii) a boiler of any required output can be obtained by assembling the required number of sections, and (iii) large boilers can be assembled easily in relatively inaccessible boiler houses. They are not suitable for production of steam for sterilising soil, as sludge removal facilities are usually inadequate. Sizes suitable for heating up to about 4000 m^2 of glass are available.

Mild steel welded boilers are made in a wide variety of forms, some sectional. Generally one-piece boilers of welded construction are of greater interest. A typical welded steel fire tube boiler is shown in Fig. 23.5. Combustion takes place in a furnace which is usually of rectangular shape, and the gases pass through a number of tubes immersed in the water. A single unit can be suitable for heating up to about 6000 m^2 of glass.

Economic boilers are horizontal shell-type boilers with one furnace tube in which combustion takes place and one, two or three passes of fire tubes. Economic boilers are designated 'dry back' or 'wet back' according to whether the rear of the combustion chamber is formed from a layer of firebrick (dry back) or a water jacket (wet

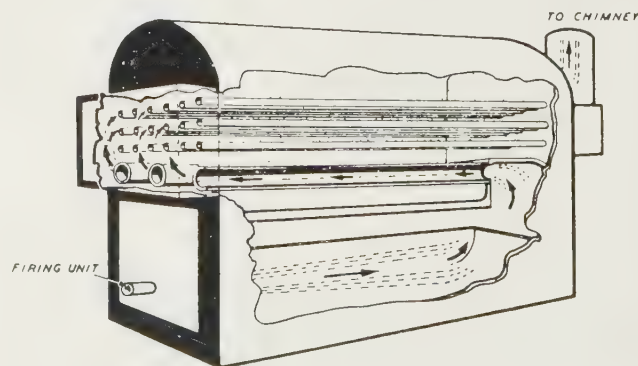


Fig. 23.5 Welded steel shell fire-tube boiler.

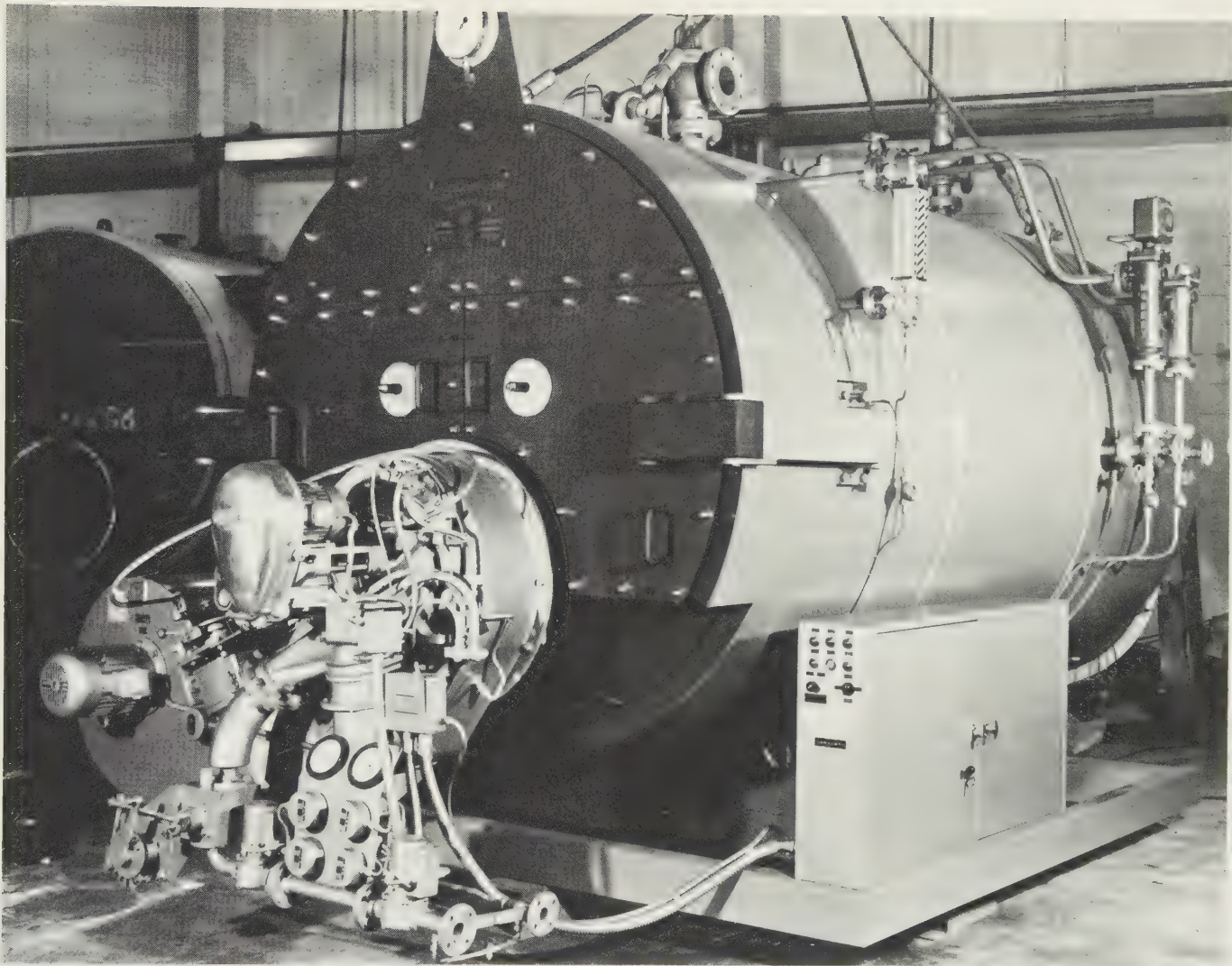


Fig. 23.6 Triple-pass 'Economic' packaged steam boiler fitted with dual fuel (gas/oil) burner. (B & E Boilers)

back). In the dry back type the firebricks become incandescent during combustion, assisting in complete combustion of the fuel and reducing smoke emission. On the other hand, maintenance of the bricks must be carried out, and this can be expensive.

Vertical boilers are economical in floor space but have a disadvantage in the larger sizes in requiring considerable head room. There are two main types. The first is very simply constructed and consists of a fire box in a vertical shell with a small number of water tubes crossing the fire box. The initial cost is low, but so is the thermal efficiency,

so this type is only used for intermittent duties, such as steam sterilising. The second and more efficient type, known as the vertical multi-tubular, has a larger number of fire tubes between the combustion chamber and the chimney.

Packaged boilers are usually based on shell-type economic boilers and consist of the boiler mounted on a steel frame with all its controls and fittings. The only connections requiring to be made are to the fuel, electric power and heat flow and return systems. The packaged boiler is thus a completely self-contained unit (Fig. 23.6). This type of

presentation has the advantage to the buyer that negotiations have only to be carried out with one manufacturer to secure a working system. The manufacturer guarantees and takes responsibility for all components. In addition, the components are all matched to the boiler, so that there is a better chance of satisfactory performance from the start of the boiler's working life.

Boiler feed water treatment

Most water supplies contain dissolved substances which, if not removed or neutralised, will cause a build-up of scale on the heating surfaces or cause corrosion in boilers and also in other parts of the heating system. Scale formation is caused by heating or evaporation of hard waters. The scale causes damage by acting as an insulating layer, which prevents efficient contact of the boiler water with the metal. The metal becomes overheated and is either burned away by the hot gases or collapses under the pressure in the boiler. Water softening can be carried out in a number of ways, either externally to the boiler or internally in the boiler itself. External treatment is usually by the soda lime or base exchange process. Internal treatment consists of the regular addition of measured doses of chemicals to the boiler feed water.

Low temperature corrosion

All oil fuels contain some sulphur, ranging from a trace in the lighter viscosity fuels to approximately 3% in the heavy oils. During the process of combustion the sulphur combines with oxygen to form sulphur dioxide and sulphur trioxide. These, combined with water vapour, form sulphurous and sulphuric acid respectively. If these acids, initially formed as vapours, are allowed to cool and condense on the boiler surfaces, they will cause corrosion. Mild steel is much more liable to this type of corrosion than cast iron. The critical surface temperature for mild steel is approximately 54°C, and below this temperature corrosion by sulphur acids proceeds rapidly.

On some hot water heating systems it is desirable to operate the heating pipes at temperatures below 54°C when the demand for heat is low. Under these conditions the return water to the boiler may be maintained above this temperature by the use of a three-port valve. This allows the boiler to produce hot water which is mixed in the valve with return water to provide the required water

temperature in the glasshouse. The three-port valve is controlled by a glasshouse air thermostat and modulates between making all the water by-pass the boiler at no heat demand and returning all of it to the boiler at maximum heat demand. When starting up from cold, corrosion can be kept to a minimum if a shunt pump is introduced to pump hot water directly from the flow to the return main. Where medium or heavy oil is being burned, this pump may be used to circulate water through the preheating coil.

Heat distribution

The main requirements of a greenhouse heating system are:

- (1) Sufficient heat exchange surface should be installed to provide the required air temperature under the worst normal conditions.
- (2) The distribution of heat input should be designed to provide a uniform temperature throughout the structure. Wherever possible, the greenhouse should be constructed on a level site and with a level ridge, otherwise even temperature distribution is impossible.
- (3) Control should be initiated from a sensitive detector, aspirated and screened against loss or gain of radiant heat.
- (4) The heating system should be designed to have a low thermal inertia, in order to respond as quickly as possible to changes in demand for heat.

Types of heating system

Low-pressure hot water-system

Modern greenhouse hot water systems use small-bore steel heating pipes of 32 or 38 mm inside diameter. These provide greater flexibility and lower thermal inertia than the 100 mm diameter cast iron pipe systems formerly much used and still occasionally found.

The pipe layout consists of a series of loops of pipe, screwed or welded together, running along the crop rows or beds (Fig. 23.7). The pipe loops may be close together, between crop rows for example, or fixed to greenhouse support stanchions, or be more widely spaced alongside



Fig. 23.7 Pipework for high-speed hot water heating system. A loop of 32 mm pipe is provided for each double row of tomatoes, the pipes of alternate loops being supported on the concrete dollies on which roof supports are mounted. The aspirated-screen thermostat and the irrigation pipes are also shown. (photo B. R. Smith)

pathways, and used as railway lines for crop handling and transport systems.

The size of the pipe is determined by the amount of heat output required and the number of loops of pipe which will conveniently fit in with the method of planting the crop. Sizes between 25 and 50 mm diameter are generally used, and the most suitable size for any condition should be carefully calculated. As a rough guide, two

32 mm pipes are required to give the same heat output as one 100 mm pipe used in the older systems.

Elaborate pipe supports are not usually necessary; just something to hold the pipe at least 50 mm clear of the greenhouse floor. If the pipes are to be used as railway lines adequate supports must, however, be provided, and the extra cost can be considerable.

A pipe union, or a piece of rubber hose, can be used to connect the heating loops to the main. Both allow the loops to be removed easily, but the latter has the additional advantage that the distance between the loops can be altered to suit different crops.

A well designed high-speed hot water system, in conjunction with automatic control, will maintain a substantially constant temperature in the plant zone throughout a house or block of houses, and due to the low thermal inertia of the system there will be little variation in temperature during periods of rapidly changing heat demand.

Automatic firing is essential. Where solid fuel firing equipment is to be used, it is essential to make sure that any heat produced after the unit has shut down will not lead to local boiling.

The system is extremely adaptable. Prior to planting, the soil can be warmed sufficiently within 48 hours of turning the heat on by simply laying the heating pipes on the soil. Later in the season, if flexible connections are used, it is easy to modify the pipe layout to suit other crops.

This is an attractive system of heating, especially for small or medium-sized nurseries specialising in a limited number of crops.

Medium-pressure hot water system

In this system, water is used above its normal boiling point of 100°C. The water is prevented from boiling by pressure applied by an auxiliary unit, or by steam trapped in the boiler. Hot-water boilers can be used with the auxiliary unit, the operating pressure and hence water temperature being determined by the type of boiler. A steam boiler has to be used if the second method of pressure application is adopted, and in this case both the flow and return mains must be connected well below the water line.

Glasshouse systems are often designed with a flow temperature of 116–121°C and a design temperature drop of 22–33°C between flow and return. The pressure in

such a system typically ranges from about 2–4 bar. The pipe layout in the houses is very similar to that of a low-pressure hot water system except that, due to the higher operating temperatures, the diameter or length of pipe installed can be reduced. Because of the fairly high temperature drop, smaller mains and pumps are needed. Capital cost may be 15–25% less than that of an equivalent low-pressure system, depending on the size and layout of the installation. If steam pressurisation is used, hot water for heating and steam for soil sterilisation can be taken from the boiler at the same time, but the total amount of heat available in the two forms is limited by the boiler capacity.

Direct steam systems

In direct steam heating systems the steam is distributed through insulated mains, and the heating pipes within the structures may be arranged in the form of continuous loops or 'trombones', each terminating in a steam trap. Single steam pipes running in one direction from a steam header to a condensate main cause temperature gradients, especially when controlled automatically under light load conditions. With steam at about 2–3 bar few heating pipes are needed and inexpensive systems with low thermal inertia can be designed. On–off control is generally most suitable. Disadvantages are a high pipe temperature which may be unsuitable for adjacent crops and may burn if touched; noise; and a higher maintenance cost than with hot water heating.

Steam-to-water calorifiers

Where steam is required on the nursery for sterilisation but hot water is the favoured heating system, use of steam-to-water heat exchangers is required. A calorifier is a heat exchanger consisting of a series of tubes arranged in a container in such a way that heat is easily transferred through the walls of the tubes from the steam to the water. Steam pressures of between 1 and 8 bar are used. With low-pressure steam a large area of heating surface is required for a given output; thus, if the cost of a calorifier is to be kept low, the steam pressure should be as high as other factors allow. Calorifiers are arranged so that the water is circulated through the container and over the tubes, while the steam passes through the tubes. The steam gives up its heat and condenses, the condensate

being returned to the boiler. The 'water side' (or secondary side) may be designed as for conventional low-pressure or medium-pressure systems.

Air heating systems

There are two systems in which heating is by circulation of warm air. In the first, heat is produced inside the glasshouse in an oil-to-air exchanger unit. The products of combustion are discharged to atmosphere, so that, properly installed, there is no danger of contamination of the air by fumes. Most units are automatically fired and employ a fan to blow the air either from the top or bottom of the unit or through ducting. The ducting across the house is often made of sheet metal and is semi-permanent. Branch ducts consisting of thin-walled collapsible polyethylene tubes, perforated along their length, are fastened on to the main duct at appropriate points. Some heat is given off from the ducting, but most is provided by warm air which issues from the holes in the tubes. The tubes are flexible, light and easy to install. They can be fixed at the most suitable position in the glasshouse for the crop, and at the end of the season the tubes can be rolled up and stored in a small space. Long life cannot be expected from the tubing but the replacement cost is reasonably low.

For technical reasons, air heaters should burn gas oil or gas. Where high temperature lifts are required or large areas of glass are to be heated, the relatively high cost of this fuel is a disadvantage, and consideration



Fig. 23.8 Ducted warm-air heating system with a duct between each double row of plants. (photo B. R. Smith)

should be given at the planning stage to centralising the heat production unit in order to burn cheaper fuel.

In the second system, heat is generated outside the glasshouse and conveyed as steam or hot water to the heat exchange units.

The uniformity of horizontal temperature distribution depends on the type of unit (ducted or non-ducted) and the temperature lift required. Where more than frost protection (about 6°C temperature lift) is required, a well designed ducted system will give a better horizontal and vertical temperature distribution. The temperature distribution from a ducted system can be as uniform as that from a small bore pipe layout.

The disadvantages of ducted air heating systems are:

- Effective soil-warming prior to planting is more difficult to carry out. This is important for growers of early planted crops, particularly tomatoes.
- The ducts are best placed at less than 1 m above soil level, and where crops are grown in raised beds the tendency towards narrower paths makes it difficult to accommodate the ducts in the paths. Placing them above the crop level increases running costs by producing large vertical temperature gradients and as the ducts age and become less transparent, light transmitted to the crops is reduced.

The main advantages are:

- Positive air movement through the crop is obtained. This is useful in combating spread of fungal diseases.
- Good temperature control is easily achieved, as air heating systems have low thermal inertia and therefore respond quickly to changes in temperature. However, a fairly wide temperature swing must be tolerated where oil-to-air heaters are used, since many starts and stops each hour (cycling) will lead to rapid wear of components.
- The polyethylene ducts are easily rolled up to provide a clear, unobstructed working area for cultivation and soil sterilisation.

Glasshouse ventilation

The main function of a glasshouse ventilation system is to prevent air temperature rising above a desirable level in

summer. In addition, it serves to introduce fresh air and the carbon dioxide necessary for plant growth and to remove excessive humidity. Plants absorb about 75% of the solar radiation they receive. Some of this energy is used in the process of photosynthesis but the larger proportion is used in transpiration – the evaporation of water from the tissues by means of which the rise of plant temperature is limited. Transpiration increases the relative humidity of the glasshouse air and this has to be kept to an acceptable limit by ventilation. Research has shown that for tomatoes, for example, the maximum desirable temperature is 24°C, and even short periods at temperatures above 27°C are detrimental to fruit quality and yield. Maximum temperatures for flower crops are lower than those for tomatoes.

Where ventilation is inadequate, glasshouse air temperature may be 13–16°C above ambient during summer days. Adequate ventilation can reduce this difference to 3–6°C under the worst normal conditions. The quantity of radiant heat received by a glasshouse is related to the



Fig. 23.9 Ridge-vent motors and limit switches in a wide-span glasshouse. (*Electricity Council*)



Fig. 23.10 A series of 0.6 m (24 in) extractor fans in a block of Venlo glasshouses. (*Electricity Council*)

base area of the structure. An air-flow of $0.03\text{--}0.04\text{ m}^3/\text{s}$ per m^2 of base area provides adequate cooling on the hottest summer days.

Natural ventilation

This is the most common. Hinged ventilators, usually at the ridge of the house, are manually or mechanically operated through various mechanisms — usually racks and pinions in modern houses. Ridge ventilators should provide an open area equivalent at least to one-sixth of the floor area of the house. Where there are no side vents, e.g. in the centre spans of large blocks, the ridge ventilators should provide an opening of 20–30% of the floor area to give good results in hot, still conditions.

Forced ventilation

Propeller fans may be mounted vertically in the side or end walls of greenhouses. The advantages are: (1) positive movement of air through the crop provides better gaseous

exchange at each plant; (2) capital cost of a fan-ventilated new greenhouse block with forced ventilation may be lower than that with natural ventilation; (3) it is a useful method of improving under-ventilated but structurally sound houses; (4) it is well suited to ventilation of plastic greenhouses. Disadvantages are: (1) higher running costs; (2) dependence on electricity supply; (3) temperature difference between inlet and exhaust air; (4) fan noise.

Temperature variations and noise can be minimised by careful design. The general relationship between temperature difference and throughput of air is shown in Fig. 23.11. For glasshouses a rate of 0.03 to $0.04\text{ m}^3/\text{s}$ per m^2 is adequate, while 0.02 to $0.03\text{ m}^3/\text{s}$ per m^2 is suitable for most crops in polyethylene-covered greenhouses.

Extraction fans should be mounted in a side wall of a multispan block, with air inlets on the other side. This causes the air to flow at right angles to the ridges and gutters. If the air moves parallel to the ridges, it tends to take the path of least resistance and avoid the crop, moving through the apices of the structure, so that the crop is inadequately ventilated. With cross-ventilation the gutters tend to force the air down into the crop. Spacing of the fans can be up to 15 m. Fans are usually controlled in groups, each group being switched by an air thermostat set at a progressively higher temperature.

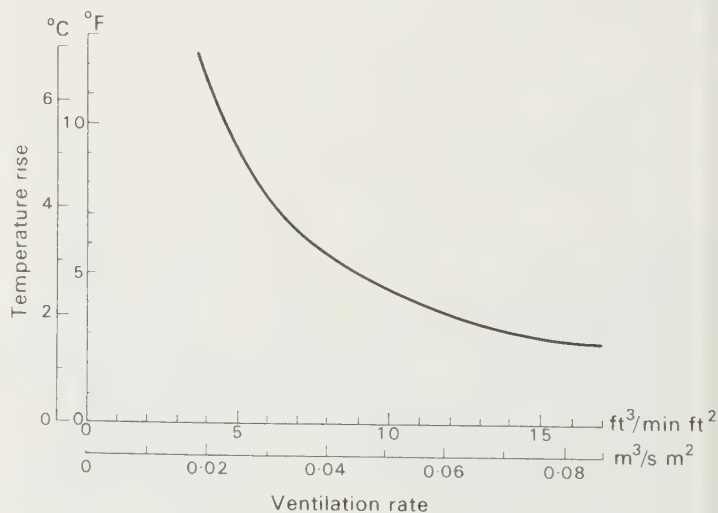


Fig. 23.11 Calculated temperature rise related to ventilation rate in a cropped glasshouse when the solar radiation intensity inside is $630\text{ W}/\text{m}^2$. (*Silsoe Research Institute*)

The air inlets may be set manually. In winter a small, high-speed inlet (or inlets) needs to be directed away from the crop to allow mixing with the warmer air inside. In summer, a large slow-speed inlet can be directed straight into the crop. A top-hinged side-wall ventilator set slightly open for winter and wide open for summer provides a practical solution.

Switching of the ventilation fans may be regulated by positional micro-switches on the ventilation inlets, so that the first bank comes on at a 'crack' for winter ventilation, and the last bank only comes on when the vent is wide open. The ventilators themselves are then controlled and driven by conventional motorised vent-regulating equipment such as is normally found in naturally ventilated greenhouses.

Variable fan-speed controls are available but the group switching system is cheaper and generally satisfactory.

Control of heating and ventilation in greenhouses

The low thermal inertia of greenhouse structures tends to cause the internal air temperature to follow outside temperature fluctuations very closely. This is not the case in normal brick- or stone-built buildings where the structure tends to store up heat in warm weather, releasing it when the outside temperature drops. Greenhouses also differ from other buildings in their thermal response to wind and sun. Thus, the internal temperature in a greenhouse can rise steeply on a cold but sunny winter or spring day.

Heating and ventilating control systems must have low thermal inertia to enable them to respond rapidly to changing requirements, and must be sensitive so that there is a minimum time-lag before remedial action begins. Some form of reflective screen is required for temperature sensors and, in addition, a sample of the greenhouse air should be continuously drawn over the sensor so that it does not measure the temperature of a pocket of stagnant air. Unscreened and unaspirated sensors can be up to 13°C above true air temperature in bright sunshine and 3–3.5°C below in clear night conditions. Various forms of aspirated screen to are available. Silsoe Research Institute developed an insulated box-type screen which contains not only the control sensors but also a thermograph so that a record of the air temperature is obtained. Simpler screens to house only the sensors are available and are less costly.



Fig. 23.12 Silsoe Research Institute-type aspirated thermostat. (*Electricity Council*)

For smaller greenhouses, simple on–off control of heating by thermostat may be most suitable. The ventilation may be controlled by a slightly more complex system using a 'mid-off' thermostat and timer to give 'pulse floating control'. This avoids driving ventilators up and down in rapid succession ('hunting').

More sophisticated continuous (modulating) control systems are used in larger greenhouses. On extensive nurseries the time required by the management for checking and adjusting heating, ventilation and CO₂ controls can be daunting, and unnoticed faults can be expensive. For these, environmental control computers have been developed and are already widely used. Computer control enables growers to achieve control targets with more certainty and enables them to refine the target schedules to maximise crop responses.

Thermal screens

Increasing fuel costs have intensified the development of energy saving measures. Thermal screens consisting of an impermeable reflective blind that is drawn across the

greenhouses at eaves level during the hours of 'darkness' can greatly reduce fuel consumption. Use of this technique can reduce overall heat loss by up to 30%.

Carbon dioxide enrichment

Air normally contains 0.03% by volume of carbon dioxide. Experimental work has shown that the concentration in glasshouses can often be lower than this, and that enrichment of the atmosphere is essential for more rapid growth, greater yield and higher quality of the product. Additional CO₂ may be provided in many ways, including from cylinders of the liquefied gas, from bulk liquid storage tanks or by burning various fuels inside the house. Burning of liquefied petroleum gas (usually propane) results in production of CO₂, water vapour and heat. For example, burning 1 kg of gas yields 3 kg of CO₂, about 1.5 kg of water and 13.56 kWh. This is a convenient method of supply at those times of the year when the heat output is of value.

Greenhouse heating calculations

When calculating glasshouse heating requirements there is much experimental evidence and experience of planning installations to show that with normal types of commercial house a *U*-value of 8 W/m²°C will cover normal thermal transmittance through the glass, the effects of wind, with a normal amount of air escape due to leakage, and losses through the soil. Small areas of brickwork should be calculated separately.

Fuel requirements can be estimated for planning purposes by use of 'degree day' charts. These show the temperature rise required to maintain desired temperature levels integrated over lengthy periods such as a week, month or season. For example, to maintain 13°C in January on the South Coast requires 234 degree days. If, for example, the calculated heat loss for a particular house is 25 kW per °C, then average heat loss for January will be

$$25 \times 234 \text{ (degree days)} \times 24 \text{ (hours per day)} \\ = 140\,400 \text{ kWh}$$

In estimating fuel requirements, account must be taken of the efficiency of the equipment. With modern oil-fired equipment efficiency is likely to be about 75% and this means that the effective calorific value is about 8.4 kWh

per litre, as opposed to the 'gross' values given in Table 23.1. Thus, at this level of efficiency, the quantity of fuel needed for the house for January would be

$$\frac{140\,400}{8.4} = \text{(approximately) } 16\,700 \text{ litres.}$$

The *U*-value for glass given above does not take account of improvements possible by use of thermal screens.

Control of conditions in horticultural stores

The efficient storage of produce is a necessary part of the production and marketing of crops. It provides a buffer between the optimum harvest date and the demands of the market for perishable crops. Alternatively, long term storage may extend the season for which crops are available, allowing the producer to enlarge his enterprise and sell a larger portion of his crop in a high quality grade.

Storage systems should take account and advantage of the characteristics of the crops for which they are intended. Crops that are being stored are alive and can cause substantial changes in the store environment. They respire, absorbing oxygen and giving off carbon dioxide, water and heat. Some crops have periods of natural dormancy whilst others may continue to develop actively during storage. Over a long storage period there can be considerable losses of moisture and of dry matter.

Temperature is the most important factor governing the rate of deterioration of stored products; most storage systems therefore depend on controlling crop temperature. Storage temperatures for the more important groups of crops are given in Table 23.2.

Table 23.2 Recommended storage temperatures

<i>Crop</i>	<i>Temperature (°C)</i>
Brassica, root and salad crops	0–2
Soft Fruit	0–2
Onions*	–1 to 0
Red beet	3
Green beans	4–7
Potatoes†	4–10
Tomatoes	8
Cucumbers	7–10

Relative humidity required; 90–95% except for onions

* Relative humidity 70–80% required

† Sprout suppressant required above 4°C. Special requirements for crisping.

Control of atmospheric composition may be used to extend the storage period. Apples respond particularly well to storage in modified atmospheres though other crops like winter cabbage can also benefit. Chemical suppressants may be used to extend dormancy or inhibit growth. An example of this is the use of sprout suppressants in potato storage. All stored products may be expected to lose weight during storage. The chief reason for this is the evaporation of water from the product into the store air. Weight loss is particularly associated with cooling of the produce. There are considerable variations in the rate at which different crops can lose water and it is often the degree of wilting that limits the effective storage life of a product. Water loss from stored produce can be minimised by maintaining a high relative humidity and constant temperature in the store atmosphere.

Crop storage environmental control systems range from the very simple to the extremely sophisticated and complex. The chief criterion in the choice of a system is the increase in value of the product that may be expected as a result of storage. Most crops can be stored under UK conditions using natural or forced ventilation, or refrigerated cool storage. Only in special cases is it necessary to consider using controlled atmospheres.

Ventilated storage

Decisions on crop storage must usually be a compromise between maintenance of ideal storage conditions to maximise storage life and provision of non-ideal conditions that will extend the life of the product sufficiently to allow sensible marketing. Inevitably the cost of producing ideal conditions is high, usually requiring refrigeration. For many crops it is possible to provide sufficiently good storage conditions by using simple enclosures and providing natural or fan assisted ventilation. Britain is normally cool enough during the winter months to enable crops to be held at near optimum storage temperatures.

Natural ventilation

Many crops that are stored in bulk can ventilate themselves by natural convection. The heat produced by the crop respiration warms the air in the bulk. It becomes less dense, rises out of the stack and is replaced by cooler air from below. If simple ducts open to the outside are provided under the bulk and there is an adequate outlet

in the roof, continuous natural ventilation will occur.

The chief disadvantages of this scheme are that freezing air may be drawn into the stack and cause damage, while during warm weather the stack ventilation may reverse and warm the crop. Natural ventilation depends on temperature difference so the top of the stack is usually warmer than the bottom. This temperature difference depends on the height of the stack, the respiration rate of the crop and its resistance to air flow. Despite these disadvantages this method is successfully used for crops like potatoes where sprouting can be controlled chemically. At storage depths of 2 to 2.5 m the natural temperature difference can result in unacceptable variations in quality by February or March in British conditions.

Skilled management is needed and the use of a layer of straw or other absorbent material on the top of potatoes is essential to prevent condensation in or greening of the upper layers.

Fan ventilation

The use of a fan to ventilate a crop store can provide better control over the storage conditions. Temperature variations throughout the store can be minimised, and by automatic selection of cool outside air for ventilation when conditions are suitable, the crop may be held at a lower temperature than would be possible with natural ventilation.

Experimental work has shown that if the weight loss from the crop is to be minimised short periods of ventilation at a high rate are best. The object of installing fan ventilation is often to attempt to extend the storage period into the spring when temperatures outside are rising. At this time the number of hours for which the outside temperature is below the required store temperature decreases; so if control of crop temperature is to be maintained, increasingly high ventilation rates are required. There is a practical limit to the maximum ventilation rate since the power required to move the air through the crop increases rapidly above 0.05 m³/s tonne and this power is turned into heat thus decreasing the cooling effect and accentuating weight loss.

Table 23.3 shows typical ventilation rates that are in current use. The rates shown are based on the whole store capacity since this implicitly allows for higher rates later in the season as the store is emptied. Cooling efficiency is likely to be greatest in bulk stores where the

Table 23.3 Ventilation rates for vegetable storage

Crop	Ventilation Rate* m ³ /s tonne
Potatoes†	0.01–0.03
Chitting Potatoes	0.05
Red Beet	0.03–0.05
Carrots	
Onions	0.04

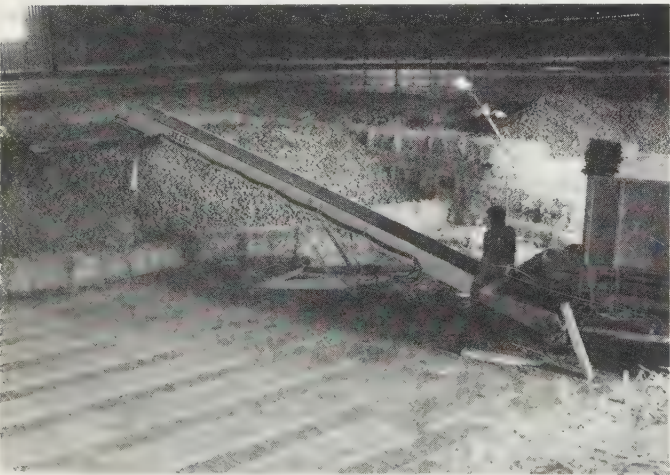
* Rates of 0.01 to 0.02 m³/s tonne are adequate in refrigerated stores
† High rates apply at end of storage period

air has to pass through the crop. In box stores the efficiency of the air circulation will influence the effectiveness of the cooling process and may make it desirable to use higher overall ventilation rates. This is not a serious problem since the resistance to air flow in a box store is usually lower than in a bulk store.

Control of fan ventilation

The use of automatic controls to select the coolest periods for ventilation is essential. The minimum requirement is a combination of a frost thermostat and a differential

Fig. 23.13 General layout of a typical large bulk store, seen being filled with potatoes. The level-floor lateral ducts seen are supplied via below-ground main ducts. (Myson)



thermostat. The differential thermostat has two temperature detector bulbs and is designed to switch on when the inside detector becomes warmer than the outside one. The frost-stat is connected in series with it and breaks the control circuit when the temperature outside falls below freezing. Adjustment of the frost-stat setting and the switching differential of the differential-stat enables the operator to control the stack temperature. More refined systems allow the setting of desired stack temperature and have provision for recirculation and mixing of ventilating air.

Refrigerated storage

Where precise control of temperature is essential and when crops must be stored into the summer when ambient temperatures are high it is necessary to use refrigeration. Simple direct expansion refrigeration systems are used in most crop stores. The liquid refrigerant is evaporated in an extended surface cooler which absorbs heat directly from the store air. The refrigerant vapour is then returned to a condensing set where the heat is rejected to ambient air. Fig. 23.14 illustrates the refrigeration circuit and a typical air cooler. This type of plant may be installed in the recirculation duct in long term bulk or box stores to extend the storage period.

Salad crops and soft fruit deteriorate rapidly after harvest unless they are cooled. Quick cooling is required and refrigeration is essential. Cooling systems used include vacuum coolers and ice-bank coolers with positive ventilation, as well as the more usual direct expansion type.

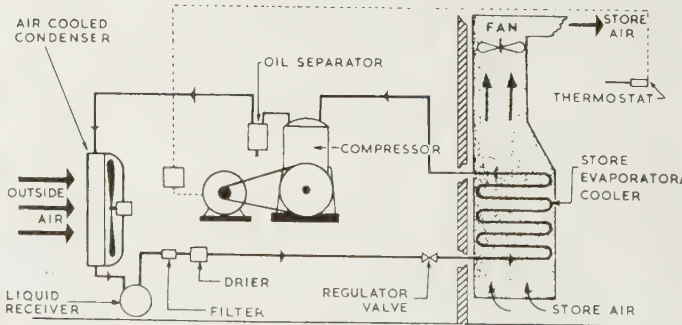


Fig. 23.14 Direct-expansion refrigeration system for a cold store.

Vacuum coolers

Vacuum cooling depends on the fact that when the pressure over free water is reduced its boiling point is lowered. If the pressure is reduced to around 5 mm of mercury, water vaporises at about 0°C. Produce like lettuce contains a great deal of water which is easily evaporated making this an ideal commodity to cool this way. The main disadvantage of the method is that it requires the loss of 1.8% of the product weight for every 10°C that it is cooled. The cooling is very reliable and does not depend greatly on the way the product is packed. Vacuum cooling is a batch process taking typically 30 minutes per cycle.

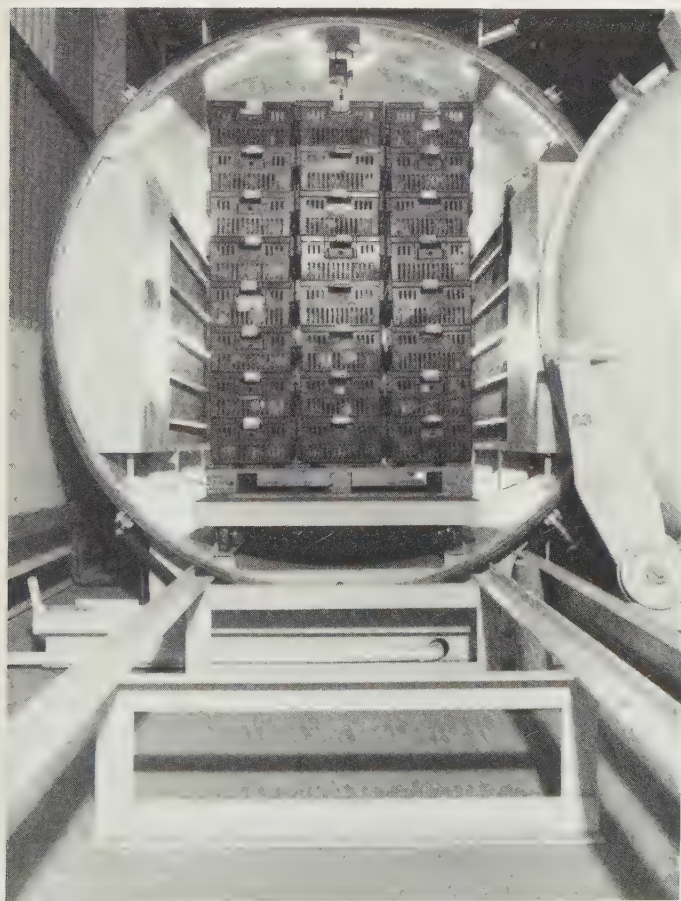


Fig. 23.15 Fully automatic five-pallet static vacuum cooler with uni-directional flow of produce as used by large-scale vegetable growers. Design data established in conjunction with Silsoe Research Institute and ADAS. (Autech)

Efficient handling of produce is essential to the achievement of cooling potential. Packed produce is normally moved through larger units on pallets running on roller conveyors. A typical five-pallet capacity cooler is likely to cost about £50 000 and to require an annual throughput of about 2500 tonnes to justify installation. It can, however, be economic where high-value crops such as celery and lettuce must be quickly cooled before transport to British and European markets on a 'cool chain' system. A five-pallet load of celery can be reduced from 20°C to 2°C in about 40 minutes; and the result can be a crisp, uniformly cooled product with a cool 'shelf life' of several days.

The cooler usually consists of a strong cylindrical pressure vessel with doors at both ends. A vacuum pump capable of lowering pressure to 10–15 mbar within 10 minutes is fitted. The water vapour produced by the cooling process is condensed by a large refrigerated cooler fitted inside the vessel.

Positive ventilation and ice-bank (wet-air) cooling

The effectiveness of conventional cooling systems is limited by the degree of contact between the product and the cooling air stream. It also depends on the ability of the cooling plant to meet peak refrigeration demands. Positive ventilation is a method of improving product – air contact. The cooling air is made to pass through the containers, usually solid-sided bulk bins with slatted floor. This results in removal of heat from the product at a high rate. To cope with this need, cooling capacity is stored in the form of ice.

Development work by Silsoe Research Institute quickly established designs suitable for commercial use. A purpose-built insulated store usually accepts a number of rows of bulk pallet boxes with slatted floors stacked three high; 'letter-box' type openings from a plenum chamber connect the air flow directly through each box. Chilled water surrounding the ice-bank is usually pumped to the top of a 'packed' tower, whence it moves downwards in counter-flow to the air before delivery to the store. In peak harvest periods large quantities of produce can be quickly cooled and safely held overnight, with minimal weight loss; the system facilitates management of both harvesting and packing.

The principles of positive ventilation can be applied to most vegetables and soft fruit. The air conditions provided

by the ice-bank are ideal for minimising weight loss though they may cause deterioration of cardboard packing materials.

Controlled atmosphere (CA) storage

The storage life of apples and some other fruits can be extended by storing them in modified atmospheres. A reduction in oxygen and/or an increase in carbon dioxide concentration results in a decrease in the metabolic rate of the fruit. Table 23.4 shows recommended gas concentrations and temperatures for common varieties of apples.

Controlled atmosphere storage requires a refrigerated storage chamber usually 50 to 100 tonnes in capacity that can be sealed to retain the modified atmosphere. Provision may also be required to scrub carbon dioxide from the store atmosphere. Essential instrumentation includes an accurate remote reading thermometer, and oxygen and carbon dioxide gas analysers. The refrigeration capacity should be capable of bringing the full store load of fruit to storage temperature within five days. The cooler is usually designed to meet the holding requirements of the store whilst maintaining a humidity in the range 93–98%.

The chamber is made gas tight by using an impermeable internal lining and special door sealing panels. A storage chamber may be tested by pressurising it and noting the time taken for the pressure to fall from 1.9 to 1.25 m bar

Table 23.4 Recommended storage conditions for some apple varieties

Variety	Air Storage Temp.°C	Controlled Atmosphere			
		Temp.°C	Without Scrubber %CO ₂	With Scrubber %CO ₂ %O ₂	
Bramley's Seedling	3.0–4.0	3.5–4.5	8–10	—	—
Cox's Orange	3.0–3.5	3.5–4.0	5	5 (<1	3 2.5)*
Crispin	1.5–2.0	3.5–4.0	8	—	—
Egremont Russet	3.0–3.5	3.0–3.5	6–8	5	3
Laxton's Superb	1.5–3.5	3.5–4.5	6–8	7–8	3
Worcester	0–1.0	0.5–1.0	7–8	5	3

* Conditions for extended storage

gauge pressure. Successful low oxygen storage conditions require a test time of 7 minutes, minimum.

After the fruit has been loaded and the chamber sealed, the fruit respires the remaining oxygen away, converting it into carbon dioxide. The oxygen level is controlled by limited ventilation of the store with fresh air. The CO₂ level is controlled by chemically or physically scrubbing it from the store atmosphere. Chemical scrubbing depends on the conversion of hydrated lime to calcium bicarbonate. Physical scrubbing employs molecular sieve techniques based on activated carbon or aluminium silicate.

Once the store has been sealed the instrumentation is the only means of monitoring gas concentrations and temperature. Failure to control either of these within close limits can result in damage to the fruit. Oxygen is usually measured by a magnetic analyser whilst an infra-red analyser is used for CO₂ measurements. Temperatures are usually measured by electrical resistance thermometer.

Ripening and maturation of fruit and vegetables is also affected by ethylene. Control of this gas in a long-term fruit store to less than 1 part in 10 million extends storage life and improves quality. Scald in Bramley apples can be controlled by such treatment. Removal of the gas is by scrubbers based on catalytic oxidation of the gas at high temperature; but economics of the process depend on effective heat recovery to minimise running costs. Measurement of low ethylene concentrations continues to be a practical control problem.

Environment control in livestock buildings

Introduction

A major factor in the efficient production of housed livestock is the control of the environment. Temperature is the most important factor though control of air speed, lighting, humidity and trace gas concentrations are also important. Table 23.5 lists the typical environmental requirements for the main classes of intensively housed stock. Stock generate heat and water vapour, both of which must be removed if a satisfactory environment is to be maintained. The simplest means of control is to ventilate the building. The rate of ventilation is used to control the temperature and providing the building structure is sufficiently well insulated and the stocking rate is high enough, supplementary heating is not normally required to maintain design temperatures for adult stock

Table 23.5 Typical environmental requirements for the main types of livestock housed in 'controlled ventilation' conditions*

Stock	Temp. °C†	R.H. %	Ventilation Rate $\times 10^{-3}/\text{m}^3/\text{s}$ kg live wt	Max. Air Speed m/s
PIGS				
Loose pen sows/ boars	13–18	60–85	0.5	0.2
Farrowing house	15–18	"	0.6	0.15
Piglet creep	21–27	"	minimal	0.1
Weaners in flat decks, 2–5 weeks	27–32	"	0.5	0.15
Porkers	15–25	"	0.5	0.25
Baconers	11–24	"	0.5	0.3
Heavy hogs	10–24	"	0.5	0.4
POULTRY				
Day-old- 0.5 kg broiler	29–32	65–70	<1.5	0.1
Broilers	18–24	"	2.0	0.25
Layers	18–22	"	2.0	0.3
Turkeys	16–18	"	3.3	—
CATTLE				
Calves 35–95 kg	10	60–85	0.5	0.1

* Normal design figures. Minimum needs are lower, often in ratio down to 1:10, and sometimes to 1:100. See text.

† For pigs, this depends on floor type, e.g. solid or slatted, or if strawed

throughout the year. During the summer months the ventilation rate should be sufficient to limit the temperature rise in the house to $<3^{\circ}\text{C}$ above ambient. In winter the ventilation rate is reduced so that the house is kept about 14 to 18°C above ambient. This usually requires a ventilation control ratio of 10:1. In some situations, for example broiler houses, a control ratio (maximum divided by minimum ventilation rate) of up to 100:1 is required. This is to allow for the changes in stocking rate as the birds grow under an 'all in, all out' stocking regime.

The temperatures shown in Table 23.5 are generally those below which the stock will begin to consume significant amounts of additional feed in order to keep warm. This temperature is known as the lower critical temperature and is affected by many factors, e.g. air speed, type of floor, number of animals in the group and their age. For young stock it may be necessary to provide extra heat. The usual source of heat is electricity or gas.

With a good standard of thermal insulation ($U = 0.5 \text{ W/m}^2\text{C}$; see Appendix 4) the maximum artificial

heat input needed for normal stocking and ventilation rates is as follows:

Type of stock	Max. heat input per head needed (watts)
Calf	350
Young piglet	150
Weaner	250
Day-old chick	10

Insulation

The levels of insulation used in livestock houses are chosen to minimise the chance of condensation and to limit the heat loss through the fabric so that in cold weather the ventilation rate can be high enough to carry away water vapour and gases whilst still maintaining the design temperature. Typical insulation levels for pig fattening houses are $0.5 \text{ W/m}^2\text{C}$ for the roof, $0.6 \text{ W/m}^2\text{C}$ for the walls and $1.0 \text{ W/m}^2\text{C}$ for the floor.

Ventilation

The ventilation system in a building should perform two functions: to control the temperature and provide a stable air distribution pattern over a wide range of external weather conditions. Air movement patterns are governed by four interacting effects. These are buoyancy, the tendency for warm air to rise, 'Coanda' effect (the tendency for air streams to follow smooth surfaces), rotary motions, and 'jets', which are rapidly moving directional air streams. In deciding how a building will be ventilated it is advisable to remember that jets are generally the most powerful of the forces that influence air movement patterns and that these can be used to dictate the primary air movement.

Fans

Intensive livestock buildings require mechanical ventilation, generally using propeller fans. Special propeller fans have been developed which, using electronic control, can be speed controlled down to 10% of their maximum. Speed control is a popular method of varying the ventilation rate of a building because the volume of air moved by a fan is directly proportional to its speed. This method of control suffers from a serious disadvantage; when the

speed of a fan is reduced the pressure that it develops is dramatically reduced. This makes the whole ventilation system very susceptible to wind interference. Careful siting of buildings and the protection of fan inlets or outlets using baffles can help to reduce these effects but cannot eliminate them.

Many modern ventilation systems overcome the wind interference problem by using fans that run at full speed all the time. Ventilation rate is then controlled by varying the number of fans in use.

Ventilation systems

The type of ventilation system chosen will depend on the class of stock being housed and to some extent the type of building. One of the four types below will cover most situations.

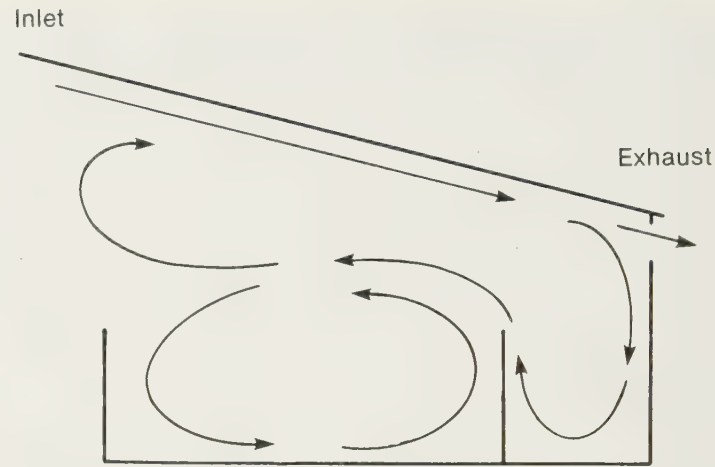


Fig. 23.16 Air flow patterns in a pig fattening pen using a controlled high-speed air inlet system.

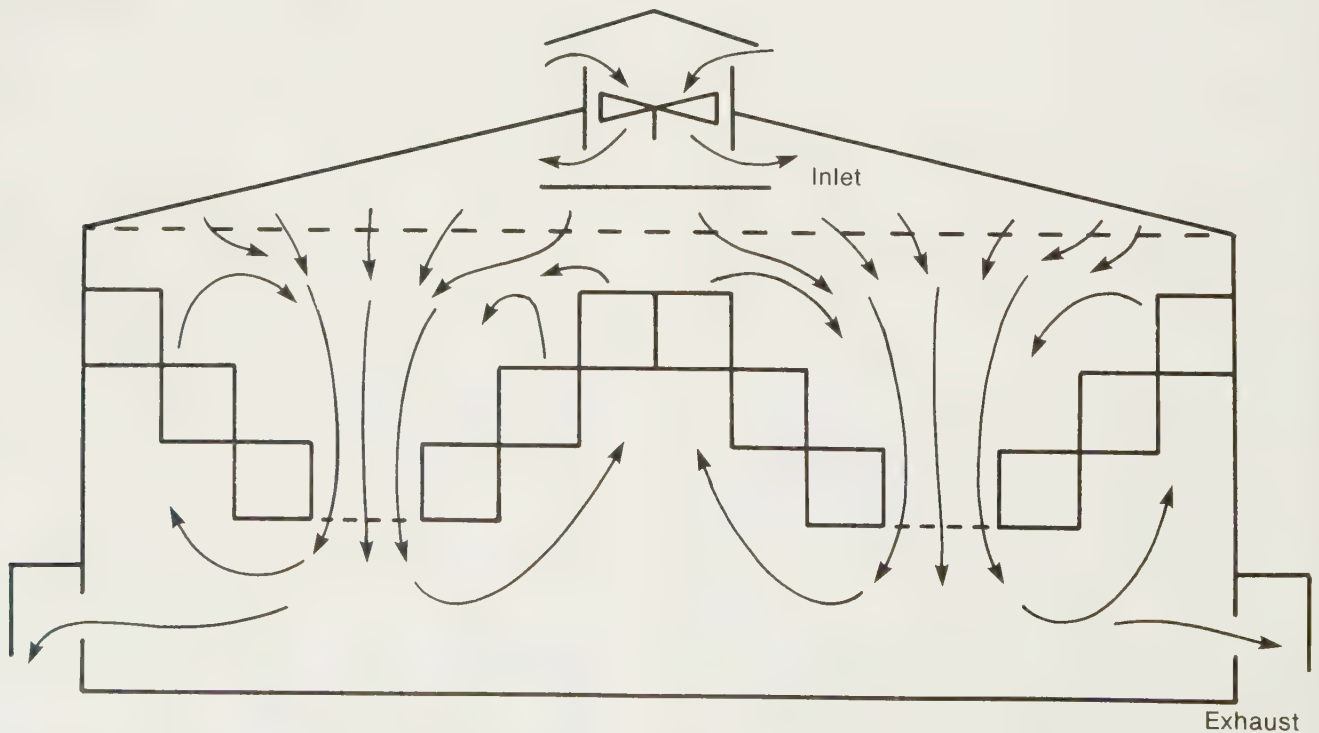


Fig. 23.17 Air movement patterns in a caged layer house with a glass fibre (diffused inlet) ceiling.

Controlled high-speed inlet: Air is extracted from the building by fans working in groups. Ventilation rate control is obtained by selection of the appropriate groups of fans to meet the cooling demand. The building is sealed, with reverse flow dampers on all fans; and air is admitted through adjustable slot openings at the eaves or ridge. The slot opening is automatically controlled so that the speed of the air entering is constant irrespective of the number of fans in use. A typical design air speed for the entry jet is 5 m/s which if maintained will result in stable distribution patterns over a wide range of ventilation rates and ambient temperatures.

Diffused inlet: Air is introduced into the building through a diffusing membrane such as a glass fibre ceiling. Air circulation patterns are determined by the convection currents generated by the stock. A typical application for this type of system is a battery cage house. Any stocking system in which the animals are restricted to specific parts of the house may be considered suitable for ventilation in this way. Ventilation rate control can be by selecting groups of fans or by speed control of fans. Air escapes from the house through baffled outlets in the sides (Fig. 23.17).

Ducted and recirculation systems: A stable air distribution system is established by using the jets produced by the outflow from perforated distribution ducts to set up the primary air flow pattern. Ventilation rate is controlled by adjusting the relative proportions of fresh and recirculated air discharged by the duct: a mixing box gives this control facility. This type of system lends itself to applications where heating and filtration are required. It is also suitable for small installations where groups of fans are impractical. The system has reasonable immunity from wind interference because the fan runs continuously at full speed.

Polythene distribution ducts may provide a practical method of improving the ventilation and air distribution in existing houses where the structure or capital cost precludes more sophisticated solutions.

Natural ventilation: Natural ventilation depends on wind and buoyancy effects (stack effect) and is commonly used for less intensively housed stock, for example, cattle. Its chief advantage is its low capital and running costs. The introduction of automatic control of natural ventilation extends the applicability of this method to intensively



Fig. 23.18 Ventilation by perforated polythene duct (top left) in battery cage house. (Crown copyright photo)

housed stock. Ventilation rate control is effected by thermostatically controlled flaps which adjust the areas of the air inlets and outlets. A further important use of natural ventilation is as a means of emergency ventilation in houses that are normally fan-ventilated.

Ventilation control systems

Effective ventilation systems without good control can give a poor environment and can result in economic loss. For example, over-ventilation during cold weather can give poorer feed conversion and growth rates due to the house temperature falling below the design level.

The simplest form of automatic control employs a thermostat to switch the fan on and off. Such a system results in unsteady temperatures and air movement in the house. Where a number of fans are used separate thermostats may be cascaded, and set so that as the temperature in the house rises, progressively more fans

are switched into use. This method of control is effective but requires careful setting of the thermostats.

Step control is a more reliable method of controlling groups of fans. Cooling capacity is divided into a number of approximately equal steps and the system matches the number of steps in use to the demand for cooling. Deviations up or down from the set temperature result in groups of fans being switched on or off. Four or five steps of cooling usually provide sufficient precision for a ventilation control ratio of 10:1.

Where the speed of the fan is variable proportional control is often used. Stable control with reasonable accuracy is obtained by setting a proportional band width of 2°C. It is necessary to ensure that the correct minimum speed is reached with these controllers since over-ventilation will result in low house temperatures.

Where supplementary heating is provided the ventilation must be reduced to minimum before the heating is switched on. The controller will normally need to have a 'dead band' between the heating and cooling stages to ensure this.

Controlled lighting for laying hens

Windowless houses are now normally used for intensively managed poultry. The best lighting regime varies with different management aims. A typical aim is to hold pullets back a little during the rearing period, by limiting day length. As they approach the point of lay, day length is gradually increased.

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Diesel Engines

The criterion of efficiency in a heat engine is the maximum amount of work obtainable from a given amount of fuel. The overall efficiency of an engine may, therefore, be obtained by expressing the heat-equivalent of the useful work done by the engine as a percentage of the heat value of the fuel used. In general terms, internal combustion engines are about twice as efficient as steam engines in this respect. Efficiencies of 10 to 15% in steam engines are good, and the best efficiency obtainable is about 25%. Overall efficiencies of 22 to 25% are not unusual in petrol engines, and some diesel engines reach values of 35%. The highest efficiencies (about 42%) have been obtained by a combination of a diesel engine and a steam engine, in which the waste heat from the diesel engine is employed to assist in the raising of steam.

Two main types of internal combustion engines are commonly used on farms: (a) petrol; (b) diesel. Vaporising-oil engines which start on petrol are in principle very similar to petrol engines: this type has become obsolete, being replaced by diesel in larger sizes and mainly by petrol in very small ones. Small light-weight fuel injectors developed primarily for use in car engines are likely to contribute to further economic development of small diesel engines for use in agriculture. There are important differences between petrol and diesel engines.

Engine and tractor test reports indicate engine efficiency by the 'specific fuel consumption', which is expressed as the weight of fuel (g) used per kW hour. Typical optimum specific fuel consumptions for modern diesel engined tractors are about 240–300 g gas oil per kW hour available at the pto. The specific fuel consumption is higher at light loads.

Diesel engines

The term 'diesel' is applied to a variety of types of engine which run without the necessity of an electric spark to cause ignition of the fuel. In 1890 Akroyd-Stuart took out patents involving a cycle in which pure air was compressed, and the fuel was injected later in order to avoid pre-ignition. These engines were of a low-pressure type, requiring a hot bulb or other external method to ignite the charge. In 1892 Dr Diesel patented a cycle in which the fuel was caused to ignite spontaneously on its injection into the cylinder, owing to the high temperature set up by the compression of the air. The type to which the term 'diesel' is generally applied today is the solid (or airless) injection, compression-ignition (CI) engine.

The cycle of a typical modern four-stroke diesel engine is as follows:

- (1) On the induction stroke pure air is drawn into the cylinder.
- (2) On the compression stroke this air is compressed at a high compression-ratio, so that the temperature is raised to a high value.
- (3) Towards the end of the compression stroke the fuel is injected into the combustion chamber in the form of a fine spray. The temperature of the air in the combustion chamber is sufficiently high to ignite the fuel as it enters, and combustion of the mixture of fuel and air produces the working stroke.
- (4) As the piston moves upwards on the final stroke the exhaust gases are expelled from the cylinder in the usual way.

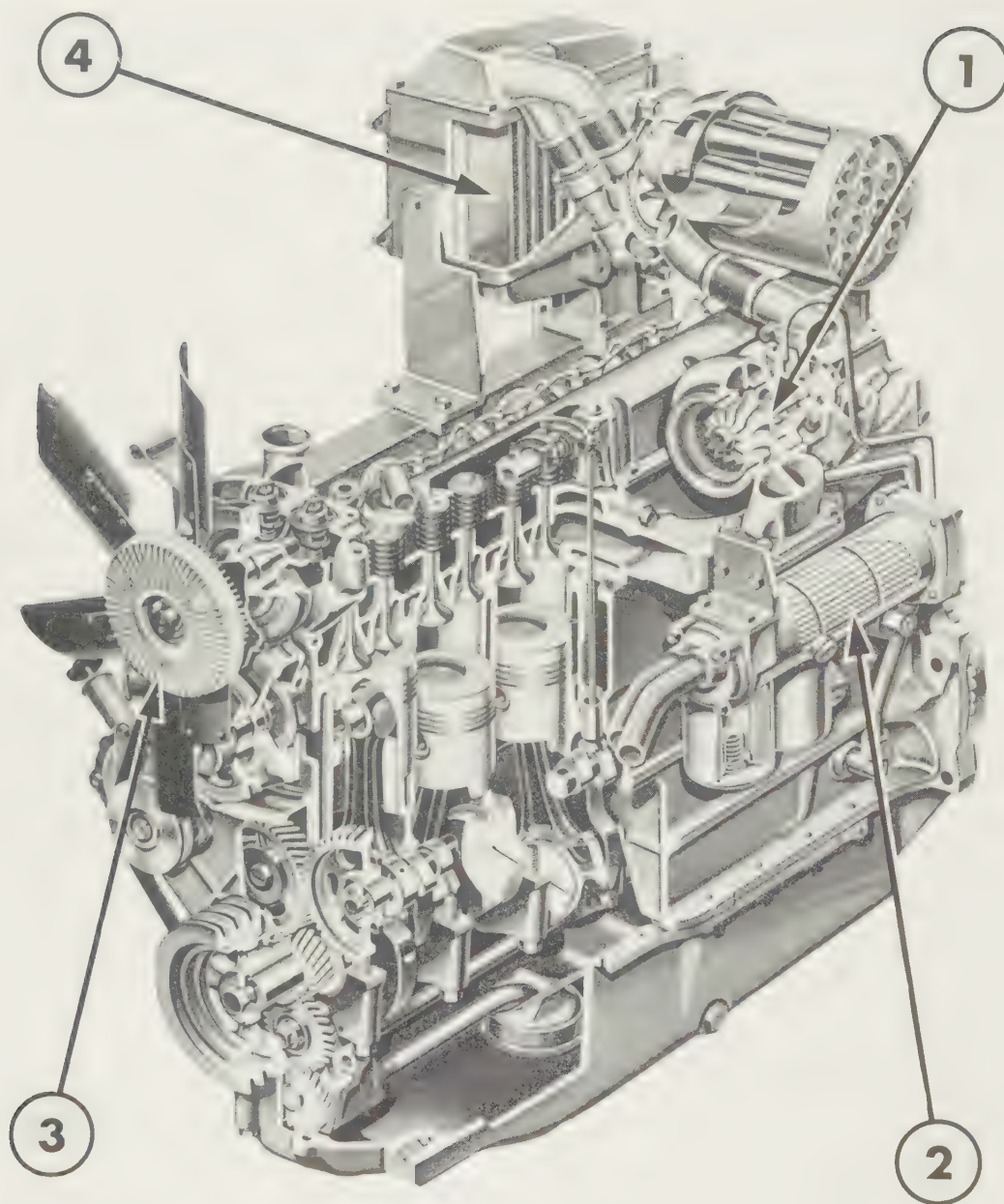


Fig. A1.1 Sectioned diesel tractor engine with direct injection to short-stroke cylinders. Pistons have an annular depression in the crown. Valve operation is by push rods and overhead rockers. Features include turbocharger 1 with air-to-air inter-cooler 4, externally mounted oil cooler 2 and viscous fan drive 3. See also Fig. A1.6. (*Ford New Holland Series 30 six-cylinder*)

The diesel cycle thus differs in many important respects from the Otto cycle. The compression of pure air instead of a mixture of fuel and air makes it possible to employ high compression pressures without any danger of detonation. Thus, whereas the usual compression-ratios employed in petrol engines are not more than 8 to 10:1, the compression-ratios employed in CI diesels range up to over 16:1 and result in compression pressures of up to 5000 kN/m². The temperature of the compressed air at the moment of fuel injection is generally about 750°C.

The injection of the fuel takes place over a period equivalent to about 15° to 30° of rotation of the crankshaft. Injection usually commences from 10° to 20° before the piston reaches top centre, but both the point of commencement of injection and the duration are variable. The fuel is injected at pressures ranging from about 5500 to 20 000 kN/m². The gradual combustion of the fuel and expansion of the gases give an impulse to the piston that is more sustained than that produced in the petrol engine, and the higher compression-ratio makes high efficiencies possible.

Injection of the fuel

In the original diesel engines the fuel was injected by the use of a high-pressure air blast. This was inconvenient and sometimes dangerous, and modern diesels employ solid or airless injection, achieved by use of the fuel pump and injection nozzle. An important factor in the rapid progress achieved by diesels in recent years has been the commercial production of reliable high-pressure metering fuel pumps and injection nozzles. Many types of pump and nozzle are now obtainable.

The 'distributor' type fuel injection pump

For many years it was general practice with multi-cylinder diesel engines to employ a separate pumping element for each cylinder. With the distributor pump, one injection pump barrel and plunger is used to supply all cylinders in turn, and a distributor connects the pump to the individual injectors as required. The whole fuel metering arrangements are built into a compact, totally enclosed unit, leading to economy in cost without any sacrifice of efficiency. For this reason the distributor pump has quickly become very widely used.

A typical distributor pump has its single injection pump

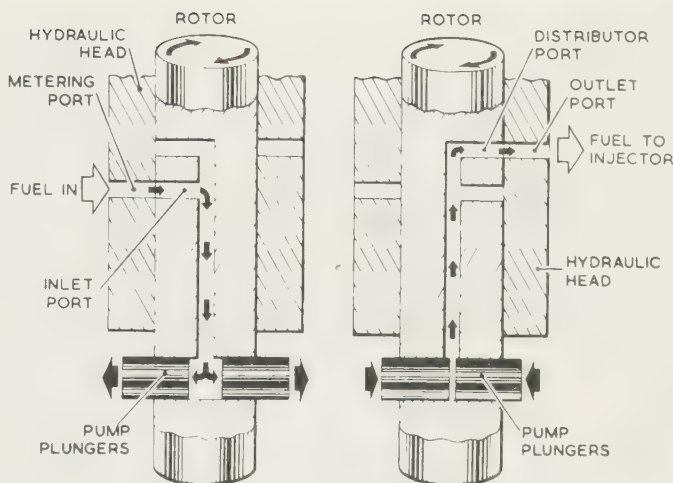


Fig. A1.2 Distributor-type fuel injection pump. (CAV)
Left: Position of rotor during charging of injection pump cylinder.

Right: Position during injection stroke.

The distribution port is connected in turn to each outlet port and injector.

cylinder arranged transversely in a driven rotor which also carries the distributing ports, the governor and a fuel transfer pump which delivers the fuel via a metering valve to the inlet ports of the injection pump. The principles of operation are illustrated in Figs A1.2 and A1.3.

The injection pump has a pair of opposed plungers which are operated simultaneously by the internal lobes on a stationary cam ring. When the pump cylinder is being charged (Fig. A1.2), fuel is forced by the transfer pump through the metering valve and via one of the charging ports into the pump cylinder. The amount of fuel that enters the pump cylinder is determined by the transfer pressure and the setting of the metering valve. With the rotor in the charging position there is no connection with the outlet ports.

When injection is taking place (Fig. A1.2), connection with the fuel inlet ports has been cut off; the cams force the pump plungers towards one another, and the oil flow is connected to one of the outlet ports, and thence to one of the injectors.

The type of metering valve employed depends on whether a mechanical or a hydraulic governor is used. With the mechanical governor the governor weights are so shaped that they pivot about one edge under the

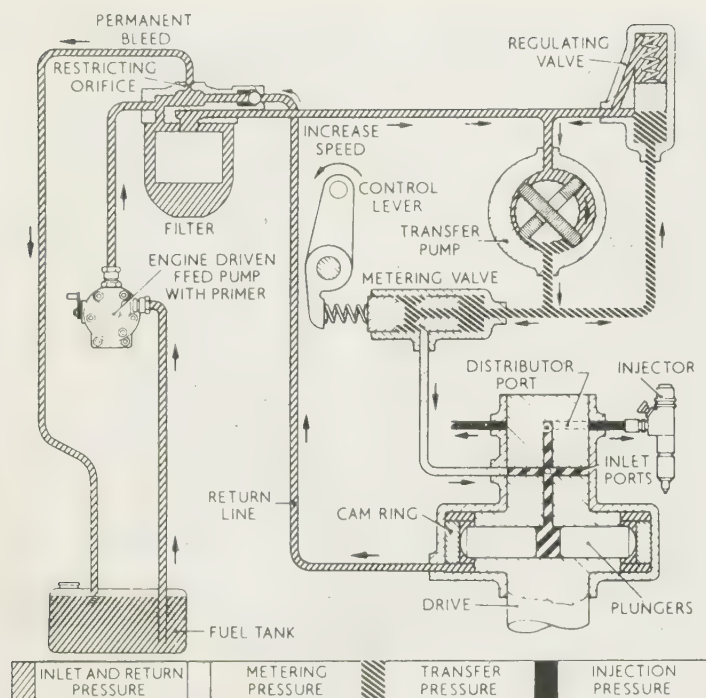


Fig. A1.3 Distributor-type fuel injection pump with hydraulic governor: general arrangement of components and fuel flow. (CAV)

influence of centrifugal force. This movement causes a thrust sleeve to slide along the drive shaft. Movement of the thrust sleeve is transmitted to the metering valve. Increased engine speed causes outward movement of the governor weights, and this closes the metering orifice by rotating the metering valve. The tension of the governor spring tends to oppose outward movement of the governor weights and to hold the metering valve in the maximum fuel position. This spring tension can be varied by moving the control lever. When acceleration is required, spring tension is increased so that it overcomes centrifugal force acting on the governor weights and rotates the metering valve towards the maximum fuel position, but as engine speed builds up, centrifugal force increases, the spring tension is overcome and the metering valve is partly closed.

In practice, the linkages are a little more complex, in order to permit stable idling, and to allow for direct control at any engine speed without need for overriding the governor.

Hydraulic governor control is based on use of the transfer oil pressure. Transfer pressure increases with increased engine speed. This transfer pressure acts on one side of a piston-type metering valve, while adjustable spring pressure acts in the opposite direction. Increased spring pressure tends to push the metering valve into the maximum fuel position; while transfer pressure tends to hold it in the idling position (Fig. A1.3). The compact general arrangement of the principal mechanisms in a commercial DPA pump with mechanical governor is indicated in Fig. A1.4.

Automatic control of injection timing is also easily achieved by employing transfer pressure to regulate the angular position of the cam ring, so that injection begins earlier or later, according to engine speed.

The fuel injection nozzle is an important part of a diesel fuel system. In the usual type a needle valve is held on to a conical seating by a coil spring, until the pressure of the fuel in the delivery pipe is high enough to lift it. As soon as the pressure in the delivery pipe falls below the correct injection pressure, the spring forces the valve back on to its seating and injection ceases. The size, shape and length of the injection orifice influence the type of spray produced. The design of the combustion chamber and the method of injection influence the efficiency of combustion, and one of the objects in designing cylinder heads is to secure 'turbulence' in order to mix the fuel and air as thoroughly as possible.

Many successful designs employed indirect injection into a pre-combustion chamber in which the fuel was injected across a mass of rapidly rotating air. Use of a pre-combustion chamber has, however, been generally discarded in favour of 'direct' injection systems, very often in conjunction with use of a turbo-charger. Turbulence is frequently achieved in an open type of cylinder head by a suitable design of the piston top.

Turbo-chargers

A turbo-charger is a type of air pump which draws in air from the air-cleaning system, compresses it, and forces it into the engine cylinders when the inlet valves open. This provides a positive pressure in the inlet manifold, and in conjunction with alterations to the fuel injection equipment can result in a significant increase in engine power. The turbo-charger is located on the exhaust manifold and is driven entirely by the exhaust gases. The turbine housing

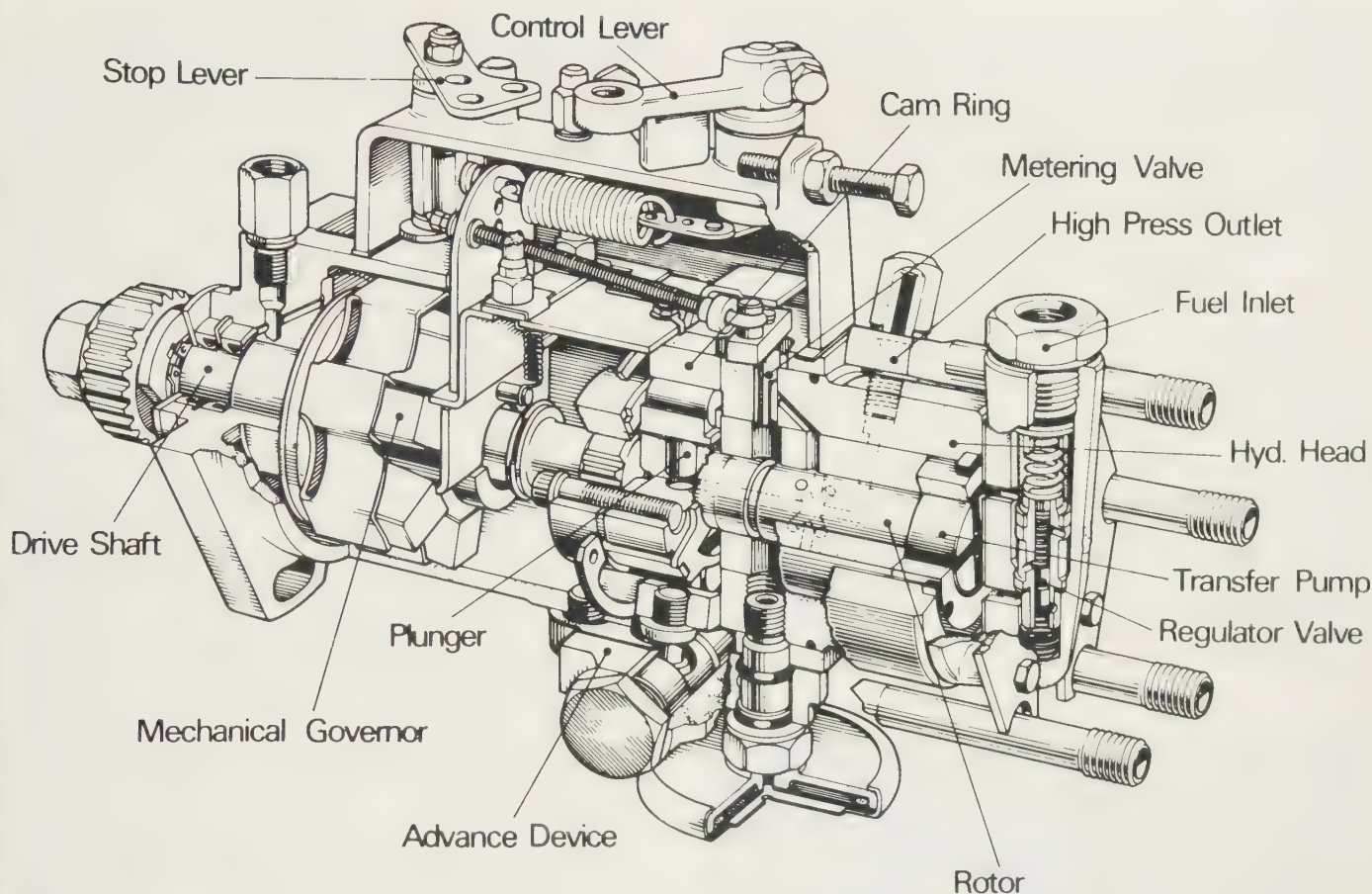


Fig. A1.4 General arrangement of DPA fuel injection pump with mechanical governor. (CAV)

is designed with a venturi to increase air speed at the turbine blades, with the result that the turbine wheel rotates at a speed of well above 10 000 rpm depending on turbine diameter and air requirement. The compressor wheel at the other end of the shaft can increase the amount of air entering the cylinders by up to 50%, and considerably more fuel can be burned economically. Combustion efficiency can be improved, leading to a better specific fuel consumption and less exhaust smoke (Fig. A1.5).

A more complex turbo-charger system (Fig. A1.6) used on high-powered engines uses about 10% of the compressed air from the turbo-charger to drive a separate tip-turbine fan that fulfils two functions: (a) it cools the compressed air in an air-to-air inter-cooler before it enters

the engine cylinders, thereby increasing air density and the volume of fuel that can be effectively used. Typical temperature reduction at 30°C ambient is from 140°C to 70°C. (b) The air from the tip-turbine fan, after passing through the inter-cooler, is used to aspirate dust particles that have been separated by centrifugal action in the air cleaner, and deliver them to atmosphere via the engine exhaust system.

A turbo-charger used in a medium to light tractor engine needs to produce a high boost at low speed (in order to achieve a satisfactory torque at low engine speed) without producing an excessive boost at high engine speeds. In an advanced design (termed 'waste-gate') a spring-loaded dump valve opens and discharges the excess boost (e.g. Perkins engine in M-F 300 and 3000 Series).

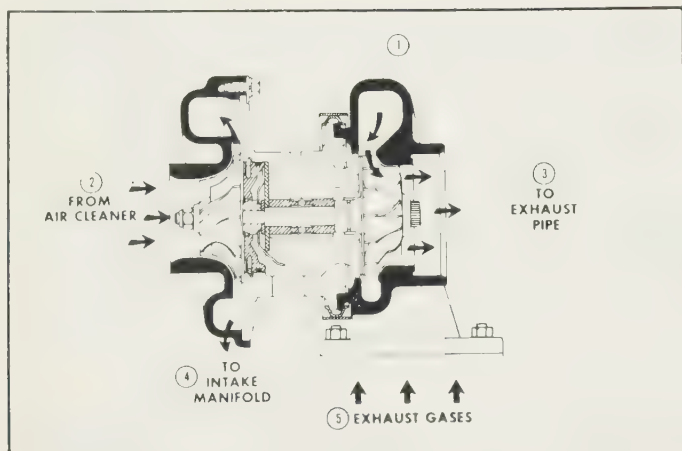


Fig. A1.5 Turbo-charger: section showing air-flow. Exhaust gases from engine flow into turbine housing (1) where a venturi establishes velocity as gases act on blades of turbine wheel. The turbine drives compressor wheel which draws air into compressor cover and delivers it to intake manifold. (Ford New Holland)

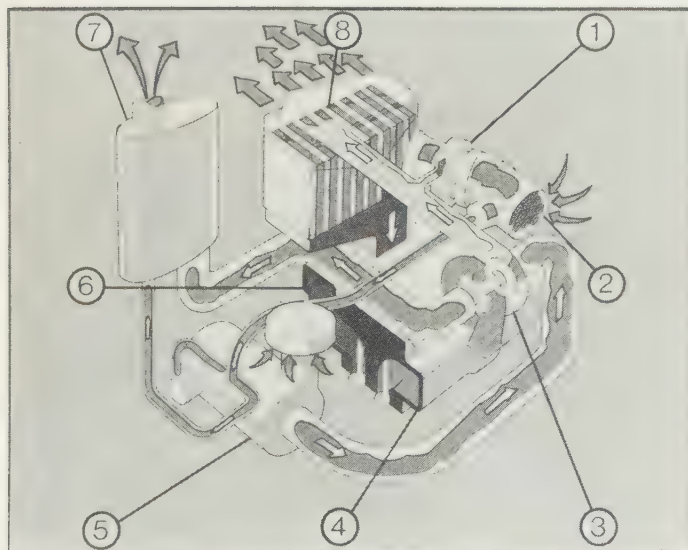


Fig. A1.6 Turbo-charger with air-to-air inter-cooler. Turbo-charger 3 draws air through main cleaner 5 and delivers it via inter-cooler matrix 8 to inlet manifold 6. By-pass compressed air powers tip-turbine fan 1 which draws inter-cooler air through cleaner 2 and delivers it through matrix 8. Scavenge pipes from exhaust 7 pass dust from both air cleaners to atmosphere. (Ford New Holland)

Cooling tractor engines

The amount of cooling needed by tractor engines varies widely with work rate and atmospheric conditions. With water-cooled engines it is advantageous to use good thermostats in conjunction with a recirculating full-flow by-pass to short-circuit the coolant from the cylinder heads directly back to the block for faster warm-up. When the engine is at working temperature, the engine fan of a high-powered tractor absorbs a large amount of power, so there is considerable advantage in a reliable method of avoiding driving the fan when it is not needed. This can be simply achieved by mounting the belt-driven fan on a viscous drive hub.

The *viscous cooling fan* (Fig. A1.1) has a bimetallic coil sensor located in the centre of the fan hub face where it measures air temperature immediately behind the radiator. At a pre-determined temperature level the sensing coil opens a valve which allows a viscous liquid to pass by centrifugal force from a reservoir into the fan drive area, within which are two sets of interlocking annular fins, one set on the drive member and the other on the free-wheeling hub body to which the fan blade assembly is attached. When the viscous liquid passes between the overlapping drive blades, the resulting drag transmits torque to the fan. The fluid is recirculated to the reservoir by a simple plate pump; and if air temperature behind the radiator falls, the bimetallic coil closes the viscous fluid entry valve, the fan drive area is quickly emptied, and the fan blades are no longer driven. Power and fuel savings are greatest when high-powered engines work on light loads in cool conditions.

Starting diesel engines

The modern CI diesel engine usually starts from cold without difficulty, and may be reckoned a more reliable starter than a petrol or paraffin engine; but with large powers, starting presents some difficulty, owing to the high compression-ratio against which the engine must be turned. Large engines may be started by an electric motor, by a small petrol engine or by compressed air. Various devices may be used to facilitate the task. One widely adopted device is a compression-release which allows momentum to be gained, and this is frequently used in conjunction with devices for increasing the heat, such as electrically heated plugs or heater cartridges.

Maintenance and adjustments

The reliability of engines may be maintained, and their annual running costs diminished, by regular attention to the essential parts. Future breakdowns may frequently be prevented by periodical checking of the lubrication, adjustment of the moving parts, etc. Cylinder heads and valves should occasionally be decarbonised, and the valves should be kept adjusted to the clearances recommended by the manufacturers.

With diesel engines modern injection systems are seldom a cause of trouble. Fuel pumps and injection nozzles should never be dismantled so long as they work efficiently, and when it does become necessary to take them to pieces the manufacturers' instructions should be carefully followed. A smoky exhaust in a diesel engine is a sign of unsatisfactory working, caused either by overloading or

by the fuel system not working correctly. If the engine runs for long in this condition, the piston, valves and injection nozzle become coated with carbon, and this will certainly cause inefficient running and may lead to more serious trouble. Turbo-chargers, with their very high rotational speeds and internal temperatures up to 700°C require specialist service, including very accurate rotor balancing.

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Transmission of Power

One of the oldest and most common methods of transmitting power from one rotating shaft to another is by means of belting. The power is transmitted through the agency of the friction between the belt and the pulleys.

When power is being transmitted, the tension on one side of the belt is greater than that on the other. If these tensions and the speed of the belt are known, the power transmitted may be calculated. Thus, if T N is the tension on the tight side of the belt, t N that on the slack side and V m/s the belt speed, the power transmitted is $(T-t)V/1000$ kW.

The tension on the tight side is usually about $2\frac{1}{2}$ times that on the slack side. There is always some *creep* of the belt over the surface of the pulley due to the elasticity of the belt; excessive creep may cause a serious loss of power. Continual slipping of the belt over the pulleys must be avoided, for it causes rapid wear of the belt, as well as loss of power. The advantages of belting are that it is economical, adaptable and safe. In the driving of farm machinery, the fact that a belt will slip under unusual demands for power provides a useful safeguard against damage both to driven machines and to the engine driving them.

Belt pulleys for high speeds are usually *crowned* – i.e. the diameter of the pulley face is greater at the centre than at the edges. This construction helps to prevent the belt working off the pulley, for when the pulley is rotating at high speed, the centrifugal force imparted to the belt causes it to move to that part of the pulley which is most distant from the shaft, i.e. the centre.

It is sometimes necessary to arrange a drive between two shafts whose axes are at right angles to one another. This can only be achieved if the middle part of the belt, as it leaves one pulley, is in the central plane of the other pulley.

For short belt drives by electric motors the motor is

mounted on a hinge, and is so arranged that the greater the power requirement, the more the motor is pulled down to its work. The result is a steady and effective drive, with greatly reduced slipping.

For situations where shafts are very close together, *V-belt* drives are often suitable. The belt is made of rubber and canvas, and often runs on split pulleys which can be adjusted to take up slack or to vary the speed. When the sides of the pulley are adjusted closer together the belt runs farther from the centre, and the effective diameter of the pulley is increased. On machines such as combine harvesters, variations of fan and drum speeds may be provided for by such an adjustment. There are British and international (ISO) standards for V-belt dimensions.

Chain drives

Chain drive is well adapted to the transmission of power at slow speeds, in situations where a positive drive is required and circumstances do not permit the use of gear wheels. A wide use is made of various forms of chain drive in agricultural machinery.

The *hook-link* type of chain is a simple form that is in common use. The links are made of malleable iron or steel. They invariably run with the open part of the hook on the outside, but the direction of travel recommended may vary with the application, and with the chain manufacturer. Sprockets for light loads may be of cast-iron. The chain may tend to climb the teeth of the sprocket unless the pitch of the teeth on the driving sprocket is slightly greater than that of the chain, while the pitch of the driven sprocket is slightly less, so that the chain is in contact with the teeth as it leaves the sprocket in both cases.

Pintle chain is sometimes used in preference to the hook-link type where greater strength is required. Neither hook-link nor pintle chain is suitable for speeds exceeding about 2 m/s (400 ft per min). On most machines of modern design the old types of chain have been displaced by *roller chains* made of hardened steel parts. These are efficient and durable, and may be operated at speeds up to 3 m/s (600 ft per min). They run on accurately machined steel sprockets.

Silent chain drives are sometimes used where shafts are close together and ordinary belting cannot be employed. The chain has, on the inner side, teeth which engage with similar teeth on specially cut sprockets. The disadvantages of this type of drive are the expense and weight of the chain, and unsatisfactory performance at high speeds.

Care of chain drives

Chain drives require adequate lubrication to ensure efficient performance and long life. When working continuously in grit, external oiling may be worse than useless; the only satisfactory method of lubricating exposed roller chain drives is to remove them periodically, and soak them first in paraffin and then in lubricating oil to which a little graphite has been added. The most satisfactory performance is secured where it is possible to enclose the drive completely and run the chain in an oil bath. Chains should not be allowed to become so slack that they tend to jump the sprocket teeth; but excessive tension is equally detrimental, causing unnecessary wear of chains, sprockets and bearings, as well as loss of power.

Toothed gears

In order that gears may transmit power smoothly, the teeth must be designed with mathematical accuracy so that they may engage without shocks, and may transmit power efficiently, with a minimum of wear and noise. The gears on such machines as potato planters, drills, etc., where the strains are not excessive, are often of cast iron. For heavy work, machined steel gear wheels are generally used. Special alloy steels, hardened by careful heat treatment, are used in tractor gearboxes and other situations where the strains may be very severe.

Spur gears are those which engage as cylinders rolling together. The smaller wheel is often called the *pinion*.

Bevel gears engage as sections of cones. They may be used when it is necessary to connect two shafts whose axes are at an angle to one another and intersect. Such gears, connecting shafts at right angles to one another, are found in drills, mowers and many other farm machines.

Worm-and-wheel gearing may be used for connecting shafts which are at right angles to one another and do not intersect. This gear gives a wide velocity ratio. The drive cannot usually be reversed, i.e. the wheel cannot drive the worm. But on some machines requiring little torque a great increase of speed may be obtained by the use of a wheel driving a worm of wide pitch.

The *rack and pinion* represents an extreme case of spur gearing, where one of the wheels is infinitely large. If the pinion is mounted in stationary bearings, its rotation causes a rectilinear movement of the rack. This device is found in such diverse situations as wheel adjustments of field machines and the adjustment for the fuel pumps of diesel engines. *Helical* gears may be used to connect parallel shafts, shafts at right angles or shafts inclined at any angle and not intersecting. The teeth are cut so as to form helical curves around the cylinder of which the gear is a segment. The gears have great strength and operate quietly; they are being increasingly used in change-speed gearboxes. End thrust loads generated by use of such gears are usually contained by use of tapered roller bearings. Synchromesh systems have been rapidly adopted to assist gear changing.

Epicyclic gears are increasingly used in tractor transmissions for speed reduction and also to provide a dual range of speeds in gearboxes. In an early simple form (Fig. A2.1) the input from shaft A is to the planet wheel carrier; and if the outer casing is allowed to revolve, the whole gear train rotates 'solid', and the speed of follower shaft B is the same as that of the driver. If, however, the outer casing with its inner ring gear is held stationary, the planet wheels rotate on their own axes, and the follower is driven at a speed depending on the relative diameters of the sun and planet gears. Efficient application of epicyclic packs to on-the-move gear changes in tractors has been facilitated by the development of compact electro-hydraulic wet disc clutch packs. A form of application illustrated diagrammatically in Fig. 2.6 has input to the outer ring gear, and for direct drive the sun gear is locked by one of two wet disc clutches to the planetary carrier. Under-drive of 22% is provided when the sun gear is locked to the stationary housing. The speed

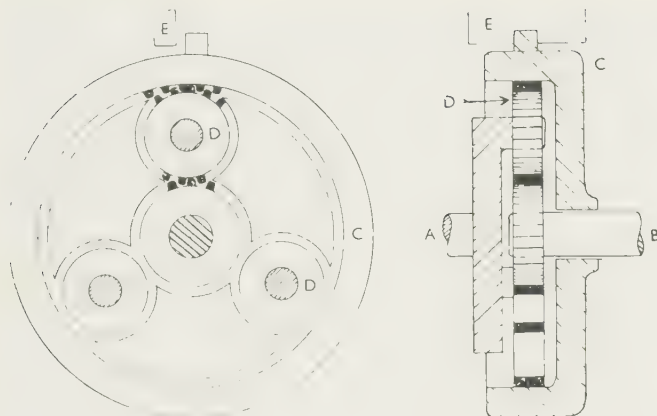


Fig. A2.1 Epicyclic gear.
A Driver, B Follower, C Outer casing, D Planet wheels, E Stop.

reduction is applicable to all of the basic gears and doubles the number of both forward and reverse speeds. Its safety on slopes and ease of operation ensures wide application of the basic principle.

Fig. A2.2 illustrates the method of operation of the differential gear on a wheeled tractor. The crown wheel of the right-angle drive carries a housing in which a pair of bevel pinions are mounted transversely. These bevel pinions engage with bevel gears attached to the inner ends of the two half-shafts. When the tractor is travelling in a straight line the bevel wheels go round with the housing as though the half-shafts were rigidly attached to

the crown wheel (Fig. A2.2(a)). When, however, the tractor turns a corner, one half-shaft must revolve faster than the other, and the bevel pinions roll on the bevel gears as shown in Fig. A2.2(b), where the wheel attached to the gear at the left of the diagram is travelling faster than the other.

Simple differential gears are no longer suitable for most farm tractors: a manually engaged lock (usually with electro-hydraulic fingertip control) has become the accepted type of equipment (Fig. A2.3). Use of automatic 'limited-slip' and 'no-spin' differentials for driven front axles is reviewed in Chapter 2. The mode of operation of the torque-sensitive limited-slip type is easily understood.

Velocity ratio in toothed gears

If a pair of spur gear wheels of diameters D and d are geared together, the relative speeds, N and n , are given by the equation $D \times N = d \times n$, i.e. the speeds are inversely proportional to the diameters. Since the *pitch* must be the same for both wheels, the number of teeth on each wheel is proportional to the diameter, and the general rule may be stated; 'The speeds of two wheels geared together are inversely proportional to the number of teeth on each.' When a train of gear wheels is used, the velocity ratio of the system may be obtained by dividing the product of the numbers of teeth on all the drivers by the product of the numbers of teeth on all the followers. The velocity ratio in epicyclic trains is a little more complex, and will not be discussed here.

Tractor gearboxes

The gearbox of a tractor is a vital part of the vehicle which has perhaps more influence than any other component on efficiency of utilisation of the engine power. Modern needs include not only provision of a large number of gear ratios, but also ability to carry out gear changes on the move, and often to engage four-wheel-drive as necessary. Synchromesh is increasingly employed, and this is often combined with a power-shift that provides two ratios with an instantaneous change from one to the other. Fig. A2.4 shows the general arrangement in one modern tractor range where engine power ranges from about 100 to 150 hp and a choice of 16 forward speeds and 12 reverse is provided. A useful feature is a reversing

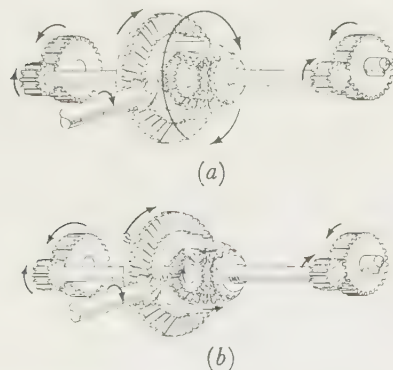


Fig. A2.2 Simple differential gear on wheeled tractor (a) Going straight ahead (b) Cornering.

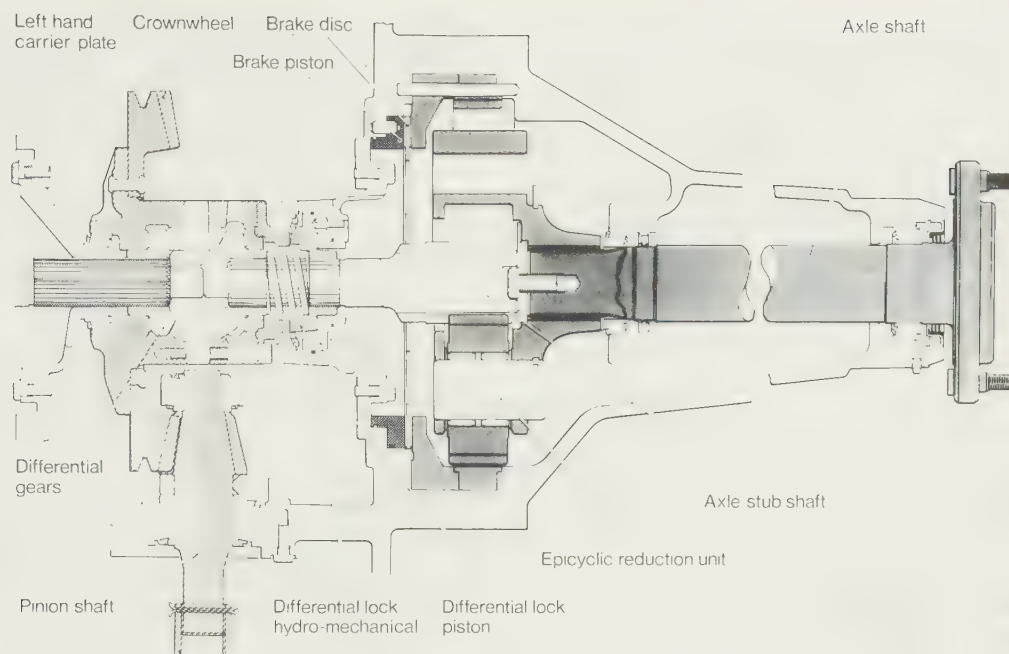


Fig. A2.3 Rear axle arrangement with hydro-mechanical differential lock having a dog-tooth coupler splined to a half-shaft. To engage, the coupler is hydraulically moved into engagement with teeth on the differential carrier. The push button operated control shows a separate warning light when engaged. At required times, e.g. headland turns, electronics can provide automatic disengagement when equipment is

raised, and re-engagement when lowered for ease of use during turn. The disc brakes have a single large-diameter oil-immersed disc on each side of the high-speed differential output shafts. The brakes are hydraulically actuated and are continuously lubricated and cooled by oil. The epicyclic reduction units are mounted at the inboard end of the trumpet housings. (*Massey-Ferguson Series 2000, 2005 and 3600*)

mechanism, manually operated, that allows a direct change from forward to the corresponding reverse gear. Some other examples of needs and trends are given in Chapter 2.

Couplings

It is frequently necessary to provide a driving connection between two shafts which are not in the same straight line, as in transmitting power from a tractor power take-off to field machines. In such a case it is necessary to provide some flexibility to permit variations in the angle between the driving and driven shafts. A device called a *universal joint* (or Hooke's joint) is used for this purpose. It consists essentially of two pivots fixed together at right angles; the driving shaft pivots on one of these and the

driven shaft pivots on the other. By a combination of the two movements, the driving and driven shafts may be run at any angle (within limits) to one another. A single universal joint operating at an angle does not deliver the drive at a uniform angular velocity. At 10° the fluctuation is small, but at 40° the total fluctuation in the position of the driven shaft relative to the drive shaft is up to 15° . This arrangement does not, therefore, result in a satisfactory drive. In practice, particularly in tractor/implement pto drives, universal joints are generally used in pairs, and the final shaft then has a uniform angular velocity, *provided that*:

- (1) the driving, intermediate and driven shafts lie in one plane;
- (2) the two joints have equal angles; and
- (3) the yokes on the intermediate shaft are in line.

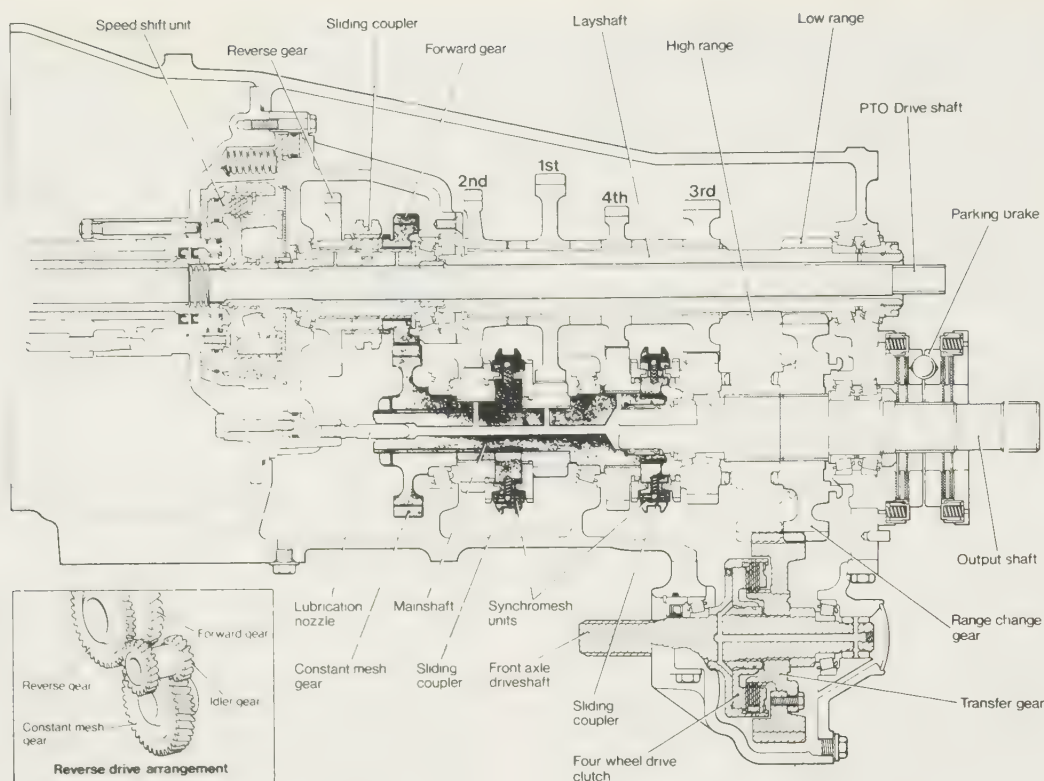


Fig. A2.4 Sixteen-speed tractor gearbox with high-low power shift and manual shuttle reverse in 12 speeds. (*Massey-Ferguson 2000 Range*) Main gearbox has basic four-speed all-synchromesh unit with constant-mesh helical gears incorporating a sliding (non-synchromesh) range-change gear on the output side. This gives high-low range in the four basic gears. The 'speed-shift' unit forward of the main gearbox is a hydraulically operated epicyclic gearset which provides a

'change-on-the-move' speed change in each of the 4×2 gearbox gears. Between the 'speed-shift' unit and the gearbox are two free-running gears, either of which may be connected to the shaft by a sliding coupler. This provides a quick 'shuttle' move from forward to reverse in any of the gears 1 to 12. The layshaft has a hollow centre to accommodate the pto drive-shaft. The mainshaft at the front end of the gearbox has a separate output shaft spigoted into its rear end.

The 1000 rpm pto allows shafts and joints for transmission of high power to be reasonably small; but vibration at high speeds can create problems unless design and construction are sound. A constant-velocity joint (i.e. with no cyclical speed variation) is attractive; but a single joint provides an angle of articulation of only 40° – insufficient for normal field work needs.

Ideally, in a pto drive, the hitch point of the implement should lie midway between the two universal joints, though this is not always practicable. BS 1495 Part 1: 1970 (AMD 2232: 1977) aims to provide for efficient drawbar and pto locations. When the hitch-point is not midway between the two joints, the angles at the two joints become unequal

during turns, and this leads to fluctuations in angular velocity in the driven shaft.

A single roller-bearing universal joint can have an operating efficiency of well over 99%, and some modern pto drives employ two double universal joints in preference to a bevel gearbox, in order to provide a drive at right angles to the pto.

Safety legislation requires meticulous attention to guarding of pto drives: improved designs make it easier to maintain safe conditions. Fig. A2.5 shows a modern conventional design with easily handled quick-release yoke at the tractor end and a star ratchet clutch at the machine power input connection (pic) end; the pto

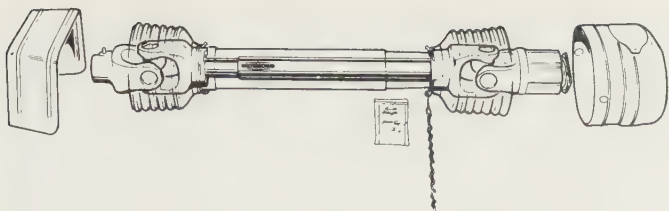


Fig. A2.5 Conventional pto shaft with quick-release yoke at tractor (left) end and star ratchet clutch at implement power input connection (pic) end. Guarding of shaft is completed by tractor mask shield and implement pic shield. (Hardy Spicer Walterscheid)



Fig. A2.6 Advanced pto shaft design, showing (left to right) quick-release lock for tractor connection; 80° wide-angle joint for smooth power transmission on turns; guard with special sliding profiles; overload release safety clutch; and key type clamp for implement connection. (Hardy Spicer Walterscheid)

guard is designed not to rotate. Other design features (Fig. A2.6) include a wide-angle joint at the tractor end and safety overload clutch with key type clamp for the implement connection. For in-built exposed shafts, flanged connections are suitable. The telescopic shafts can be 'lemon' profile or solid rectangular bar with a broached sleeve.

Bearings

The construction of the bearings used to support rotating shafting is determined by the nature of the work done. Bearings may be divided into two major classes; radial bearings, which prevent a shaft from moving sideways, and thrust bearings, which are used to withstand pressure in the direction of the axis of the shafting. Bearings of many farm implements, where the speed of rotation is low, consist of a plain hole made of chilled cast iron. For moderate speeds, brass and gun-metal are suitable

materials, while for high speeds special anti-friction alloys are used in some circumstances, and ball or roller bearings in others.

One of the main needs with any bearing is to keep abrasive substances away from it. This applies at least as much to expensive roller bearings as it does to simple journal bearings. A modern trend is towards the use of high-class bearings which are packed with lubricant and then sealed for life, no means of additional lubrication being provided.

Clutches

A clutch is a mechanism that is used to engage or disengage a machine and its source of power. Clutches may be broadly divided into two main types, (a) positive and (b) friction clutches.

Positive (dog) clutches are used on some land-wheel-driven machines to put the mechanism in and out of gear.

Modern tractor clutches are hydraulically operated. The main trend (Fig. A2.9) is towards a completely independent hydraulically operated clutch for the pto, the two drives being split by constant-mesh gears. Another method is use of a dual clutch (Fig. A2.8). The main transmission to the gearbox is via the primary pressure plate and transmission drive plate to the centre transmission drive shaft. The drive to the pto and hydraulic pump is via the secondary pressure plate and the pto drive plate to the hollow pto drive shaft. When the clutch pedal is operated the release levers first stop forward motion by disengaging the primary pressure plate. The secondary pressure plate at this stage continues to rotate with the flywheel; but further travel of the clutch pedal disengages it also, through abutment of the pto-adjusting set screws and action against the Belleville spring.

Pawl and ratchet drive

The pawl and ratchet is a device for imparting intermittent motion in one direction. The ratchet is a toothed wheel or segment of a wheel, and the pawl is the part that engages with the ratchet teeth (Fig. A2.10). When motion occurs in one direction, the pawl engages with the ratchet, but when motion occurs in the opposite direction the

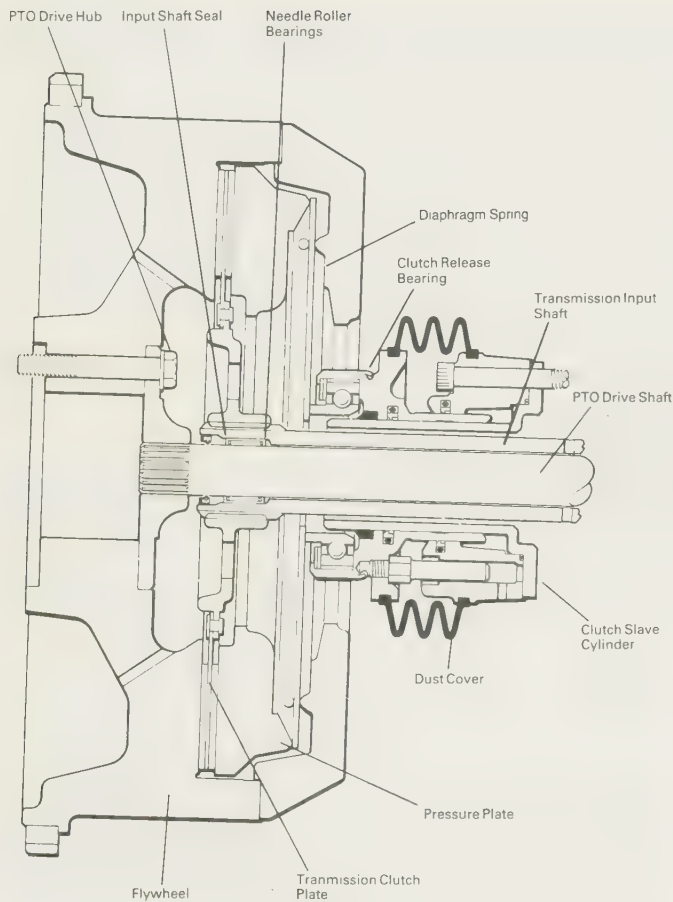


Fig. A2.7 Tractor clutch, M-F 3000 and 3100 Series. The clutch is a split torque type: the clutch plate drives the transmission and drive wheels: the shaft driving the independent power take-off (pto) and the hydraulic pump is driven *directly* from a splined hub at the centre of the flywheel. Drive to the transmission occurs when the pressure plate is moved axially forwards by its diaphragm spring: the driven plate is then clamped between the pressure plate and the engine flywheel. The transmission drive is disengaged when the clutch pedal is depressed: the pedal operates a hydraulic master cylinder, transferring oil to the slave cylinder which moves the clutch release bearing attached to it towards the clutch assembly, so relieving diaphragm spring pressure on the pressure plate, thereby releasing the driven plate. A feature of the two series is maintenance of a 1.5 bar top-up pressure in the slave cylinder to provide self-adjustment. The master and slave cylinder arrangement is automatically topped up with oil from the low-flow hydraulic circuit.

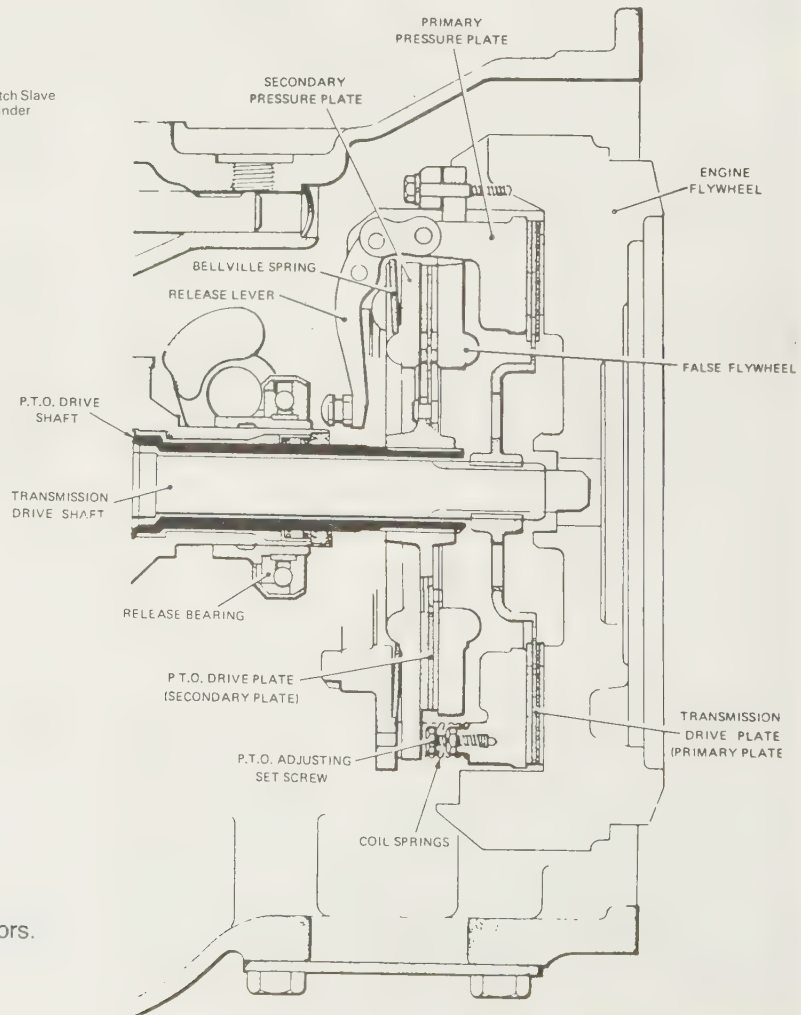


Fig. A2.8 Dual clutch for light to medium powered tractors. (Massey-Ferguson)

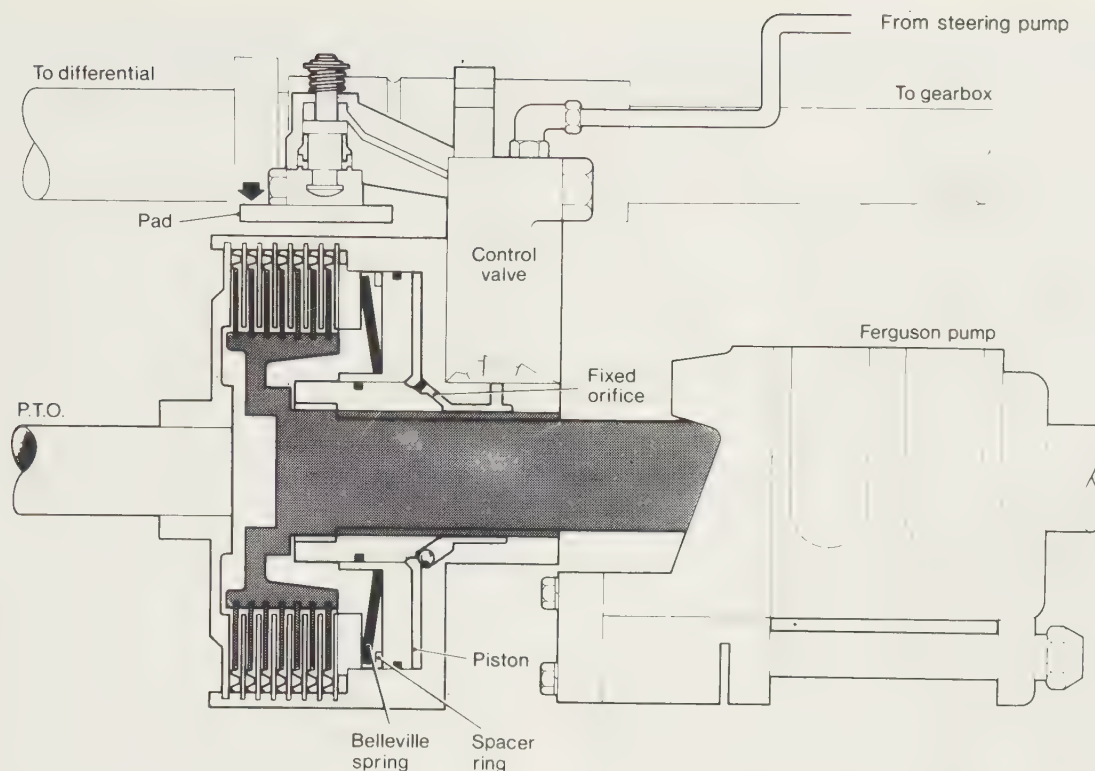


Fig. A2.9 Independent pto clutch assembly, MF-300 Series. Principal components are a hydraulically operated multi-plate clutch, a spool type control valve, and valve actuating linkage operated by hand lever on left side of tractor. The clutch is located just behind the linkage pump and is driven by the normal drive input shaft to the linkage pump. Rotation of the pto shaft occurs when the clutch driving plates (sintered) and driven plates are forced into engagement by a piston assembly operated by oil from the steering element of

the dual pump. Moving the operating lever to neutral allows oil to return from behind the piston thereby disengaging the clutch. In addition, oil is directed to the pad brake operating on the outside of the clutch casing, and so preventing unwanted rotation of the pto caused by oil drag between the clutch plates. Operating recommendations include:

1. Do not engage clutch at above 1600 engine rev/min.
2. Always move the spool valve straight into full engagement.
3. Always close throttle fully before disengaging pto clutch.

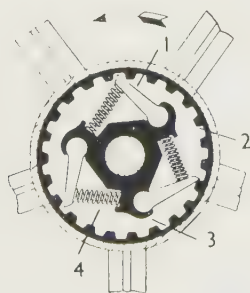


Fig. A2.10 Pawl and ratchet gear. 1 Pawl, 2 Ratchet, 2 Pawl casting, 4 Spring.

pawl slips over the ratchet teeth. This device is used to connect the wheels of such machines as drills and distributors to the live axles which they drive; a similar mechanism is also employed to drive conveyors intermittently at very low speeds, as in light distributor drives and some conveyor types of grass drier.

Cams and eccentrics

Cams and eccentrics are used for converting rotary motion into reciprocating or oscillating motion. A common type,

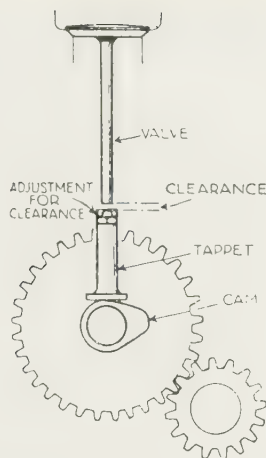


Fig. A2.11 Cam employed in valve gear of an internal combustion engine.

often used on engines for the operation of the valves, is illustrated in Fig. A2.11. A rotating shaft drives the cam, and as the tappet follows the contour of the cam a reciprocating motion is imparted to it.

The eccentric (Fig. A2.12) is essentially a crank in which the crank pin has been enlarged sufficiently to include the shaft.

The shaft, A, is keyed to the eccentric, B, which rotates inside the strap, C. The rotary motion of the shaft is converted into a reciprocating motion, and the device is used for the operation of pumps, etc.

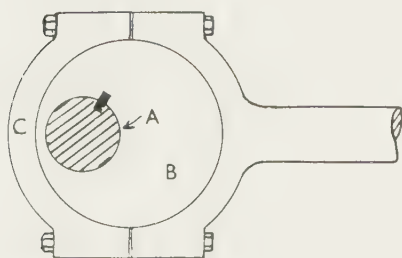


Fig. A2.12 Eccentric.
A Rotating shaft, B Eccentric, C Strap.

Brakes

A brake is a mechanism for absorbing the energy of motion of a body by converting it into heat. Brakes are used on vehicles in order to bring them to rest; they are also used on tracklaying tractors to assist in the steering. Brakes must absorb the energy that is apparently destroyed, and provision must be made for dissipation of the heat developed. Internal-expanding 'drum' brakes are the type most commonly used on agricultural trailers. Hydraulic power is increasingly used in trailer brake transmissions, but final operation of the expanding shoes lined with friction material is usually by partial rotation of a cam. Disc brakes are widely used on tractors, and these are mainly of the oil-immersed type.

Disc brakes

Tractor disc brakes are of two main types. The dry type (Fig. A2.13) consists essentially of one or more dry friction discs with friction linings on both sides. The disc is splined to the drive shaft, and the plates with friction linings are caused to grip it by an endwise thrust, usually generated by mechanical actuating discs containing balls that are

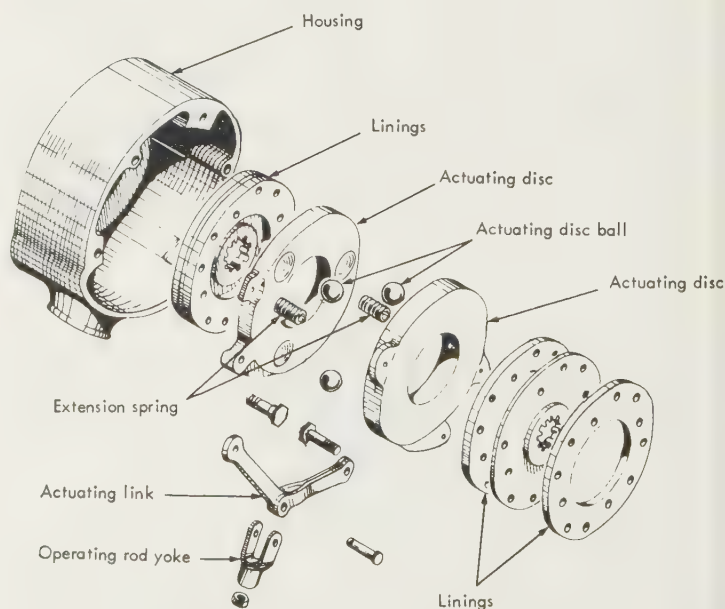


Fig. A2.13 Disc brakes (dry type).

forced partly out of their housings when the two actuating discs are rotated in relation to one another by operation of the brake pedal. The degree of self-energisation is controlled by the combined coefficient of friction of the linings and the angle of inclination of the ball seats. The movement of the actuating discs may be effected either by a direct mechanical pull or through the usual type of small hydraulic braking cylinder. The main service brake may operate through a hydraulic system, while the parking brake operates directly by a mechanical linkage on the same final operating levers.

The multiple-plate wet-disc type has become widely used. In a typical design the discs are located in the axle housings on half-shafts which rotate faster than the wheels, the final reduction being achieved by epicyclic gears. The brakes can operate either totally or partially immersed in a suitable transmission oil, and the sintered metal friction-discs are designed for dissipation of large amounts of energy. Brakes of this type are completely protected from ambient conditions, and are very reliable. Another modern rear axle arrangement (Fig. A2.3) provides for braking with use of a single large-diameter disc located very close to the differential. The brake, the hydraulically operated dog-tooth type differential lock, and the large-diameter epicyclic reduction unit which provides the final drive to the wheels, are all compactly arranged in the inner end of the trumpet housing.

Hydraulic power transmission

Hydraulic transmission is well suited to conditions requiring application of power in remote, inaccessible situations, especially where multiplication of forces is involved, where linear motion is required and where great flexibility and a very wide range of speeds is advantageous. Hydraulic transmission can be efficient where the speeds of all components are the optimum for the purpose but can have a low efficiency where great flexibility of speed is provided. The convenience of application is so important that a steady increase in use of tractor external hydraulic power is certain.

Use is made of a limited number of basic components which may be graphically represented by symbols. BS 2917:1969 illustrates and describes symbols used on an international basis. A small selection of the common basic symbols includes:

Symbol	Application
Lines of various types	Flow lines
Circle of moderate size	Energy conversion, e.g. a pump (may have P_F within) or motor (may have M within)
Square or rectangle	Regulating valve (e.g. relief valve) Selector valves (e.g. directional)
Diamond	Conditioning apparatus (e.g. filter)
Solid triangle	Point shows direction of hydraulic flow
Arrow	Path and direction of flow, e.g. through valves
Long sloping arrow across flow line or valve	Adjustable setting (e.g. control lever)
Zig-zag line	A spring
Outline cylinder/piston	A jack cylinder

Many of these symbols may be combined and elaborated, especially the valve rectangles.

One of the common types of directional valve used on tractors is a spool valve, the design of which facilitates multiple stacking of units sharing common service ports. This leads to compact control boxes with ergonomically good operating characteristics for external hydraulic services. The connection between the tractor's high-pressure system and the remote motors or rams is via armoured high-pressure hoses. These are fitted at the tractor end with standard couplings, usually of a quick-release type. All such couplings must be kept clean and should always be capped when not in use.

Fluid power

Fluid power is given by the product of flow and pressure.

In SI units,

$$\text{fluid power (watts)} = \text{Nm/s}$$

Example

A tractor hydraulic system provides a flow of $4.5 \times 10^{-4} \text{ m}^3/\text{s}$ (6 gal/min) at a pressure of 138 bar (2000 lbf/in²).

$$138 \text{ bar} = 138 \times 10^5 \text{ N/m}^2$$

The concept of force $\times$ distance is easily envisaged by considering flow through a pipe of 1 m² cross-sectional area. The force exerted on this area is $138 \times 10^5 \text{ N}$. The distance moved by each individual cubic metre when 1 m³ is pumped is 1 m.

Fluid power (watts) = Nm/s = $138 \times 10^5 \times 4.5 \times 10^{-4}$

$$\text{Power (kW)} = \frac{1380 \times 4.5}{10^3} = 6.2 \text{ kW}$$

Fluid flow

Resistance to oil flow causes loss of pressure and waste of energy. The two most important causes of inefficiency

are friction losses caused by components of the system and oil viscosity (approximately SAE 20).

Friction losses are caused by sudden changes in diameter or direction of hydraulic system oil-ways and fittings, especially by valves and connectors.

Mechanical efficiency of a hydraulic system is the ratio of the power derived from the hydraulic ram or motor to the power provided to the hydraulic pump. In poorly designed systems it can be as low as 50%, but a reasonable expectation is 75–85% for the major design operating conditions.

Measurement of Power

Dynamometers

Dynamometers are devices for measuring power. Though the dynamometer may measure all the quantities required for the calculation of the power exerted, i.e. force, distance and time, the term dynamometer is widely applied to devices which may give only a record or an indication of the force exerted. The power at any given moment may be calculated from simultaneous values of the force or *drawbar pull* and the speed. In practice, it is usual to employ average drawbar pulls and speeds in calculating the power. The average speed is obtained by noting, by means of a stop-watch, the time taken for the outfit to travel a known distance, and the average drawbar pull is obtained by use of a dynamometer.

For agricultural draught work simple hydraulic dynamometers may be used. The pressure set up in the fluid contained in a hydraulic link is transmitted to a small recording cylinder, in which a plunger acts against the force of a spring. The movement of the plunger may be read directly, or may be recorded on a moving chart. The recording type of dynamometer is sometimes employed for accurate research work, but the direct indicating type is more suitable for rapid tests and demonstrations.

By using various grades of oil from a thin machine oil to thick gear oil, almost any desired degree of damping may be achieved. Another desirable feature is that the instrument may be adapted to use over a wide range of pulls, by using springs of various strengths in the indicating mechanism. Moreover, if the dynamometer is well made, it is robust, and accurate to within 5%. The tractive power of tractors is generally called the drawbar power to distinguish it from the power delivered at the belt pulley or through the power take-off. Unfortunately, it is not possible to use a simple dynamometer to measure pulls where a three-point linkage hitch is employed.

Electrically recorded strain gauges have many uses in modern agricultural engineering research. These can measure the forces exerted in particular components of machines without replacing the components. Examples of their use include measurement of the forces set up in the three links of a tractor-mounted plough, and determination of the shock loads occurring in various parts of a tractor's hydraulic lift system when the tractor runs over bumpy land with a heavy implement in the raised position. Use for such purposes can, however, only be carried out as a research job, since fitting of strain gauges normally requires careful modification of the member being studied.

Measurement of net engine power

The net power of an engine or tractor is the power the engine can deliver for the performance of work at the crankshaft. It may be measured by means of an absorption dynamometer.

In measuring the power developed at various speeds and loads, the engine is first started with no load, and the speed of the pulley determined by means of a tachometer. The load is then increased in stages. At each stage, the speed and the torque are recorded. Beyond a certain limit, it will be found that additional loads reduce the speed of the engine to such an extent that it is in danger of stalling. When this point has been reached, no further load should be applied, for the power thereafter falls with increasing load until stalling occurs.

By plotting the values of the power for various speeds or loads, a curve indicating the maximum power is obtained.

When large powers are to be measured, mechanical absorption is not practicable, and it is necessary to employ a water brake or an electrical method. In any event, the

power developed is calculated from purely mechanical measurements involving the speed of rotation and the *torque reaction*. For example, when the power is absorbed electrically, the engine may drive a generator with a separately excited field and a controllable bank of resistances; the output of the generator may then be varied to absorb any reasonable power. The generator frame is mounted in bearings and tends to rotate with the armature, but its rotation is prevented by means of a spring balance attached to the end plate. The torque reaction is then given by the product of the reading on the spring balance and the distance from the centre of the armature.

Transmission dynamometers

In circumstances where it is necessary to measure the power delivered to a shaft without absorbing it, some kind of transmission dynamometer must be employed. In practice, modern transmission dynamometers used in agricultural engineering research and testing are almost invariably of the strain gauge type.

Belt power

Developments in technical efficiency of tractors, including availability and positioning of both mechanical pto and hydraulic power outlets at front, middle or rear of several new tractor designs, have made provision of a tractor belt pulley drive of less interest to British farmers than it ever was since driving a portable threshing drum was a common need. Even the provision of a stand-by milking machine drive is now much better met by driving a stand-by generator, as illustrated in Fig. A5.3, from a front or rear pto.

Standard OECD tests of power available at a range of engine and pto speeds, where required, now make it unnecessary to consider the need for relatively inefficient tractor belt power.

Pto power

The test of a tractor's power at the pto is usually carried out by means of an absorption dynamometer. Since pto-driven machines are normally designed to operate correctly when driven at standard pto speed, it is important

to measure power at this speed, which will normally be 540 or 1000 rpm. The relationship between standard pto speed and governor setting has been briefly discussed in Chapter 1. Tractors in general can only exert much less than full power at the standard 540 rpm speed.

Standards for power measurement

The aim of ISO work is that wherever practicable ISO standards for precise tests such as that for net engine power should eventually replace national or regional standards. ISO 1585, adapted as required to tractor engines, should therefore be expected to replace hitherto widely used national standards such as the German DIN 70020. For tractor pto and drawbar powers ISO 789 applies. Speed of adoption tends to be very slow, partly because of the painstaking development by OECD of tractor test codes and also practical organisation of testing work which ensures the use of standard test facilities and avoids duplication of tests.

The complete OECD Test Code had by 1980 become very long and expensive because of detailed tests on many tractor components. Development later of a Restricted Standard Code (see References) covers the essential major characteristics adequately, and is widely used.

Engine torque/speed and power/speed characteristics

The torque exerted by an engine is a measure of the moment which it can continuously exert. For a given gear ratio in the transmission of a tractor, any increase in load on the engine calls for a corresponding increase in engine torque. If the maximum torque available is insufficient, the engine will stall. Because tractors are designed to operate in widely varying load conditions, it is essential for satisfactory performance that maximum torque should be developed at a lower engine speed than that corresponding to maximum power. Figure A3.1 shows the torque/speed and power/speed curves for a completely up-to-date tractor engine, developed specifically for the medium power and torque needs of a tractor engine, and successfully sold world wide for that and similar uses. The test graph result illustrated is easily understood by looking first at the (lower) power output curve, beginning

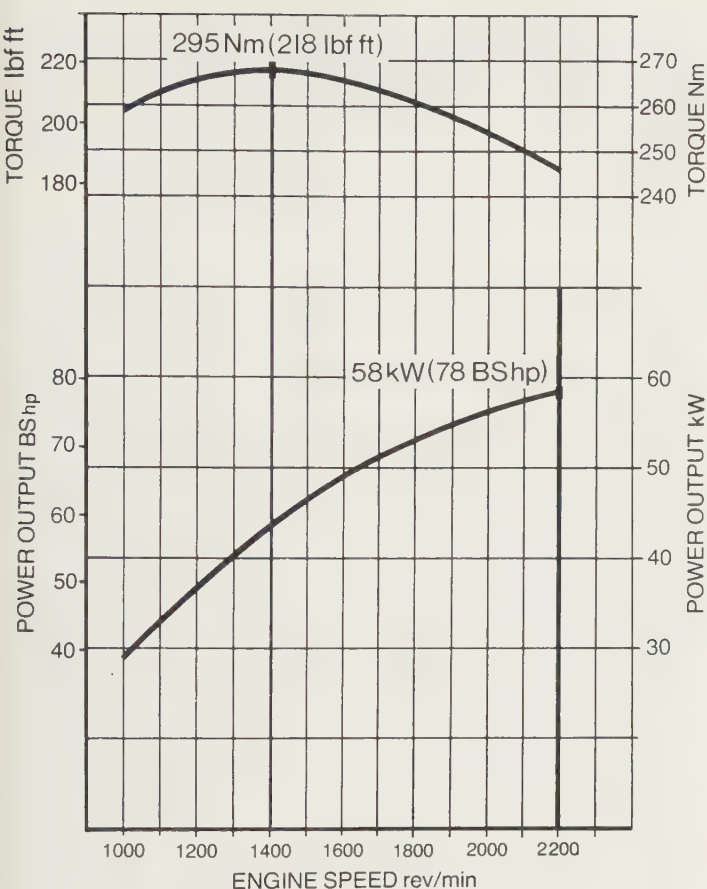


Fig. A3.1 Power/speed and torque/speed curves for an agricultural tractor engine. (Massey-Ferguson 375)

at 1000 rpm and power just under 30 kW (40 BS hp). With increasing engine speed up to 2200 rpm power output steadily increases to 58 kW (78 BS hp), but by this time, engine torque shown in the upper curve has first risen to the maximum of 295 Nm (218 lbFft) and fallen to about 246 Nm. The combined curves indicate a very satisfactory tractor engine performance in that there is reserve torque (torque back-up) at all engine speeds between 1500 rpm and its normal governed maximum. The approximately 20% torque reserve between full power and maximum torque gives the driver ample time to change down if so desired when a demand for extra torque arises. Engines with very little torque reserve are now recognised as unsuited to many field work operations, since a 10% temporary overload can cause the tractor to stall with very little warning. The percentage torque back-up from maximum power to maximum torque speeds in Fig. 3A.1 is 20%, and should be adequate to provide a torque reserve that is useful on work such as operating a forage harvester, especially if no reverse drive is available on the machine to remedy a troublesome blockage caused by engine stall.

References

- Organisation for Economic Cooperation and Development (1980) *OECD Standard Code for the Official Testing of Agricultural Tractor Performance*. OECD Publications, Paris.
- OECD Restricted Standard Code for the Official Testing of Agricultural Tractors*. C84 163 (Final). OECD Publications, Paris.

Materials Used in the Construction of Farm Machinery

It is becoming ever more necessary for farmers to know something of the properties of the materials used in the construction of their equipment.

When a part of a machine is called upon to transmit a force, it resists deformation by internal forces called *stresses*. There are three simple types of stress:

- (1) Tensile stresses, in which the forces tend to stretch the body upon which they act, e.g. a rope supporting a weight.
- (2) Compressive stresses are produced by forces which tend to shorten or compress the body, e.g. a column supporting a roof.
- (3) Shearing stresses are set up by forces tending to cause one part of a body to slide over an adjacent part, e.g. the pin that connects a tractor to an implement drawbar.

In addition to the above three simple types of stress, some parts of machines may be subjected to bending and other complex stresses which may consist of a combination of the simpler stresses. For example, the connecting-rod of a mower or of an internal combustion engine is acted upon by forces causing very complex stresses.

The strength of materials

Materials differ widely in their capacities to resist forces. The capacities of various materials may be tested by experiments with testing machines, in which known forces can be applied. The maximum force per unit of cross section that a material can withstand is called the *ultimate strength* of the material. For instance, if a steel rod 100 mm² in cross-sectional area requires a pull of 80 kN to break it, the ultimate tensile strength of the material is

$$(80 \times 10^3)/10^2 = 800 \text{ N/mm}^2$$

Elastic strength and yield point

When a body is subjected to a force that tends to change its shape, the deformation (strain) produced in the body is, within certain limits, proportional to the force applied (Hooke's law). For example, if a steel test-piece is subjected to tensile stresses in a testing machine, the elongation produced is at first directly proportional to the force applied; but if the load is gradually increased, a point called the *yield point* is presently reached, where Hooke's law no longer applies and the extensions cease to be proportional to the load, but increase at a more rapid rate. Up to this point, the test-piece will, on removal of the load, return to its original length by virtue of its property of elasticity. If loading is carried beyond the yield point (or *elastic limit*) the bar becomes permanently extended and is said to be 'over-strained'.

The elastic strength of a material is defined as the load per unit of cross-sectional area at the elastic limit. In practice, the maximum stress permitted on any member of a machine should be well below that corresponding to the elastic limit, so that the member always behaves as if it were perfectly elastic. The *factor of safety* of any member is given by the ratio breaking load/working load. The magnitude of the factor of safety required in machine design depends upon many things, including the reliability of the material and the nature of the loading and shocks that may be experienced. High factors of safety must be used for materials such as cast iron and wood, or in situations where the load is suddenly applied or is variable.

Hardness

Hardness is an important property which may give some indication of the resistance of materials to abrasion, cutting

Table A4.1 The elastic and ultimate strengths of some common materials (approx.)

Material	Ultimate strength				Elastic strength					
	Tension		Compression		Shear		Tension		Compression	
	lbf/in ² × 10 ³	N/mm ²	lbf/in ² × 10 ³	N/mm ²	lbf/in ² × 10 ³	N/mm ²	lbf/in ² × 10 ³	N/mm ²	lbf/in ² × 10 ³	N/mm ²
Cast iron	20	138	95	655	20	138	10	69	25	172
Malleable iron	35	240	42	290	20	138				
Wrought iron	55	379	50	345	40	276	30	207	28	193
Steel (0.15% C.)	65	448			48	331	42	290	40	276
Steel (0.8% C.)	105	725			80	552	57	393	63	434
Chrome nickel steel	200	1380					70	1170		
Brass castings	20	138	12	83	20	138				
Bronze; gun-metal	35	241	30	207	35	241				
Aluminium castings	15	103	12	83	12	83	6.5	49	3.5	24
Timber	12	83	6	41						

or indentation. It also has some connection with the ultimate and elastic strength of the material. Hardness tests may be carried out with many types of apparatus, and the result is given as the hardness number of the material for the particular test. For instance, the Brinell hardness number is obtained by measuring the size of the indentation produced in the material when a standard pressure is applied to a standard steel ball situated on a flat surface of the material. Hardness numbers usually give a good indication of the resistance of materials to abrasion, but substances with high hardness numbers are unfortunately not invariably markedly resistant to abrasion.

The ferrous metals

The ferrous metals include cast iron, malleable iron, wrought iron and all grades of steel. They constitute the most important group of materials used in agricultural machinery. The starting point in the production of all the ferrous metals is the pig-iron produced when iron ore is smelted in a blast furnace.

Cast iron

Cast iron is extensively used in the construction of many farm machines, owing to its cheapness and to the ease with which it can be cast into intricate shapes. In the production of castings, pig-iron is heated with coke and a

variable quantity of scrap iron and other materials in a special furnace called a cupola. An air blast passes through the cupola, and the iron melts and runs down to the bottom of the furnace, where it is drawn off in a molten state. It is then run into moulds of the desired shape, which have previously been formed in a special moulding sand by use of the appropriate patterns. The quality of the castings produced depends upon the grade of pig-iron used and the amount and quality of scrap iron and other material included in the melt. On average, cast iron contains from 3 to 3½% of carbon, 1 to 3½% of silicon and varying quantities of phosphorus, sulphur and manganese. The properties of castings vary greatly but, generally speaking, cast iron is granular, brittle and liable to break suddenly if large stresses are set up. It has, however, a tensile strength sufficient for many purposes, and possesses a great resistance to compression.

The properties of cast iron are influenced by the rate at which cooling of the castings occurs, as well as by the chemical composition of the melt. When heated above 690°C, iron combines with carbon, producing iron carbide, Fe₂₄C. On cooling, the iron carbide splits up into two or more of the following:

Pearlite, a eutectoid of Fe₃C in iron. The presence of pearlite gives toughness to castings.

Cementite (Fe₃C), which makes the castings hard but brittle.

Ferrite (pure iron), which produces soft spots in the castings.

Graphite (pure carbon), which in large amounts leads to a low tensile strength, but high resistance to compression.

The proportions in which the above four constituents are present depend largely upon the proportions of silicon and manganese in the melt. If a high proportion of silicon is present, this combines with the carbon and prevents the iron doing so, with the result that only small amounts of pearlite and cementite are formed. Manganese tends to neutralise the effects of silicon, a high proportion of manganese tending to produce a high proportion of combined carbon. Sulphur, in the absence of plenty of manganese, makes the castings very brittle, owing to the formation of ferrous sulphide.

The normal type of casting is grey when fractured, owing to the presence of some free graphite. Such castings are fairly soft and easily machined. When the carbon is present mainly in the combined form, the fracture is white and the castings are hard and brittle. Addition of such metals as aluminium, nickel, chromium, molybdenum, etc., to castings, with subsequent heat treatments, can produce great hardness and strength.

Chilled cast iron

If cast iron is cooled very quickly, most of the carbon remains in the combined state and the casting produced is white, hard and brittle. It is frequently desirable to produce castings that have one or more faces very hard, in order that these parts may better resist abrasion, while the bulk of the casting is of grey iron, for toughness. This may be effected by the use of an iron *chill* instead of moulding sand on those faces of the mould where hardness is required. Where the molten metal comes into contact with the chill, it is cooled rapidly; this part of the casting becomes white and glass-hard, but is prevented from shattering easily by the tougher grey interior or backing. The chemical composition of the melt must be carefully controlled if a chill of uniform depth is to be produced. The process of chilling is of special importance in the manufacture of plough shares for light duty.

Malleable iron

Ordinary grey cast iron has little resistance to shocks. In situations where castings need to possess some of the

strength and toughness of forgings, grey cast iron is unsuitable, but malleable iron may be employed. It is made by annealing or decarbonising white cast iron. The first step in the process is the production of hard white castings. These are then made malleable by one of two main processes, the Black Heart or the White Heart (Réaumur) process. In the Black Heart process, the castings are packed in burnt clay, bone ash or sand, and heated for 3 to 4 weeks in an annealing furnace. The cementite of the original castings is thereby decomposed into ferrite and free *amorphous* carbon. In the White Heart process, the castings are packed in iron ore and heated for about 10 days; this is an oxidising process, the carbon of the castings being oxidised by the ferric oxide in the ore. In both processes for the production of malleable castings the final effect is a casting that is tough, ductile and suitable for machine parts that are required to withstand shocks. Such castings are used in farm machines for a wide range of couplings and fastenings where hammering, bending or tensile stresses must be withstood. When malleable castings fail, it may be due either to unsoundness in the original casting or to incomplete annealing.

Wrought iron

Wrought iron is manufactured from pig iron or cast iron by the removal of carbon and silicon in a reverberatory or puddling furnace. The hearth of the furnace is lined with iron ore, and as the heating proceeds, the carbon is oxidised away and the silicon produces a molten slag, which may be squeezed out of the spongy ball of wrought iron produced. After much squeezing, hammering, rolling, welding and reheating, bars of wrought-iron are obtained. The metal is fibrous, ductile and eminently malleable. It can be bent, sheared, punched, worked under the hammer when hot and welded at 1600°F (871°C). It is never molten. It is used where an easy weld is necessary, as in chains, and in situations where considerable strength is required and the form is simple. It has been largely superseded by mild steel, which is cheaper.

Steels

Steels are produced by the removal from pig-iron of a large proportion of the carbon and as much as possible of the silicon, phosphorus and sulphur. Two main processes

are employed, the Bessemer and the Open Hearth. The furnace is lined with lime, and the phosphorus in the melt combines with the lime and produces basic slag, a valuable by-product, widely used as a fertiliser. Steels may be divided into a few main classes: cast steel, mild steel, high-carbon and special steels.

Cast steel

Cast steel contains about 0.25% carbon. It is harder and stronger than cast iron and is ductile. Great care is needed in the production of steel castings, for molten cast steel is not as fluid as cast iron and tends to form a honeycomb structure owing to bubbles. The castings are made under pressure and are subsequently annealed. They are employed in preference to cast iron where great strength is required and the form is only moderately intricate.

Mild steel

Mild steel (0.1 to 0.5% carbon) is very commonly employed for beams, rods, etc., where the shape is reasonably simple. It can be bent, sheared and forged, and can be machined by high-carbon steel or special tool steels. Its breaking tensile stress is about 450 N/mm^2 .

High-carbon and special steels

Steel which contains a high proportion of carbon may be hardened by heat treatments. Very hard steels are required for such purposes as cutting other steels or resisting continuous abrasion. In steels used for high-speed cutting-tools, the percentage of carbon may be diminished and various other metals added in the manufacture: for instance, the addition of manganese or chromium produces steels that may be used for cutting-tools or high-grade ball-bearings, and tungsten helps cutting-tools to remain sharp when they become very hot. Nickel steels are elastic and ductile. The elastic strength of some of the special steels is very high.

The heat treatment of steels

The properties of steels may be modified by processes of heating and cooling called *heat treatment*. For example, if a steel containing a sufficient proportion of carbon be

heated to 800°C (a red colour) and quenched in water, brine or oil, the steel is hardened by the process. Any steel with a carbon content of more than 0.5% is appreciably hardened by such treatment, and the higher the carbon content up to about 1.2%, the greater is the effect. But after hardening, the material is often very brittle, and it must be tempered if resistance to shock is required. Tempering consists of heating to about 500°C (a blue colour) and quenching from this temperature. The material loses most of its brittleness and a little of its hardness in the tempering process. For a given steel, the more rapid the quench, the harder (and more brittle) the material becomes. Oil has a slower quenching effect than brine, and brine is slower than water.

The hardening and tempering of parts of farm machines has become an important process in their manufacture. Steel plough breasts and shares, cultivator points and buckrake teeth are given suitable heat treatments under carefully controlled conditions, in order to produce the necessary resistance to abrasion or bending.

Annealing

In the manufacture of steel forgings or castings, enormous internal stresses may be set up, either by the actual forging process or by unequal contraction on cooling. These forces may be so great in steel or malleable castings that if the castings are allowed to cool before annealing, they may fly (break) in the cooling. Annealing consists of heating the articles to about 900°C for half an hour, and then turning out the furnace and allowing the oven to cool very gradually. This process, which takes place before hardening, if that also is required, effectively disposes of the internal stresses in the materials.

Case hardening

Wrought iron and mild steel are relatively soft, and cannot be appreciably hardened by ordinary heat treatments. They can, however, be given a hard surface by a process called case hardening. By this process it is possible to produce articles that are both resistant to shocks and extremely hard at the surface. The objects to be hardened are packed in iron boxes with a carbonaceous material, such as animal charcoal or a mixture of 3 parts of wood charcoal and 1 part of powdered bones, and are heated to about 900°C for 5 to 10 hours, according to the depth

Farm Machinery

of hard case required. The carbon combines with the iron of the materials, producing the hard cementite, Fe_3C . When they are cool, the articles are unpacked from the boxes and are then reheated alone to about 800°C and quenched in cold water in order to harden the cases.

A very thin, hard case may be applied to small articles by dipping them in molten potassium cyanide. The process is, of course, a dangerous one in unskilled hands, owing to the highly poisonous properties of potassium cyanide.

Non-ferrous metals

Copper

Copper is a soft, fibrous metal which is easily bent and sheared, and may be brazed with powdered borax as a flux. It is used in the form of wire, especially for electrical equipment, and in the form of small pipes, which may be bent cold. At low temperatures, it is safe at $1\frac{1}{2}$ tons/in² (21 N/mm²) but it becomes 'rotten' at high temperatures.

Zinc

One of the most important properties of zinc is its resistance to atmospheric corrosion. It is used as a protection coating for iron in the form of plain sheets, corrugated sheets and wires. Zinc-coated iron is termed *galvanised* iron.

Lead

Lead is a soft, heavy metal that is occasionally used alone for ductile sheets where resistance to corrosion is required. It is also extensively used in some of the alloys employed in high-speed bearings.

Tin

Tin is a very malleable metal, widely used as a protective coating for such ironware as comes into contact with human foods. Dairy utensils are frequently constructed of tinned iron, and tin is also an important constituent of certain alloys. It is, however, an expensive metal, and its use for dairy utensils is diminishing, in favour of such materials as stainless steel and aluminium.

Aluminium

Aluminium is a very light metal which is widely used for irrigation pipes, dairy utensils, electric cables and alloys. It is cheap, and its lightness (0.09 lb per cubic inch or 0.002 g/mm³) and moderate strength make it an attractive material for a variety of purposes.

Alloys

Alloys are mixtures of two or more metals, typical examples being brasses, bronzes, babbitt metal and white metal.

Brass

Brasses are alloys of copper and zinc. There are two main types of brass, one having about 70% copper and 30% zinc, and the other having about 60% copper and 40% zinc. The first type is soft, and is used in the manufacture of tubes, wires, etc., while the other is much harder, and may be used for castings. Various metals added to brasses modify the properties. Thus, the addition of a little lead makes for easier machining, tin gives increased resistance to corrosion, and manganese imparts additional strength to the alloy.

Bronze

Bronzes are alloys of copper and tin, the most important being gun-metal, which has an average composition of 88% copper; 10% tin; 2% zinc. It is used for bearings in which steel shafts revolve, and also for engine fittings. It is easy to cast, stronger than cast iron and does not corrode easily; but it is expensive on account of the tin contained in it. Phosphor bronze has an average composition of 89.5% copper; 10% tin; 0.5% phosphorus. It has all the properties of gun-metal, but is much stronger, and is used for pump rods, special bearings, etc.

White metal

The average composition of a good white metal is 90% tin; 6% antimony; 4% copper. It is an expensive metal which is sometimes used in high-speed bearings such as the 'big-end' bearings of internal combustion engines. One

of its most important properties is its low melting point, which causes it to 'run' if lubrication fails. *Babbitt* metal is a white metal in which part of the expensive tin is replaced by lead. Its properties are similar to those of white metal.

Solder

Solder consists of a mixture of about 40% tin and 60% lead. In the process of soldering, a flux is generally used with the objects of cleaning the metal, reducing the surface tension (which causes the drop of solder to remain spherical) and preventing oxidation. Zinc chloride is an easy flux, but it is not safe for electrical work owing to its hygroscopic properties. Rosin in alcoholic solution is fairly

satisfactory, and some of the proprietary fluxes consist mainly of overheated rosin with a little zinc chloride.

Ceramics

Research and development work at Silsoe Research Institute and by manufacturers show that some ceramics have high potential for use on soil-working parts of cultivation implements on account of great hardness and resistance to abrasion. Comparable figures for hardness have been reported as follows:

Material	Typical hardness (kgf/mm ²)
Soil (flint, quartz)	1100
Steel component (typical)	450
Hardfacing (typical)	700
Alumina ceramic	1200

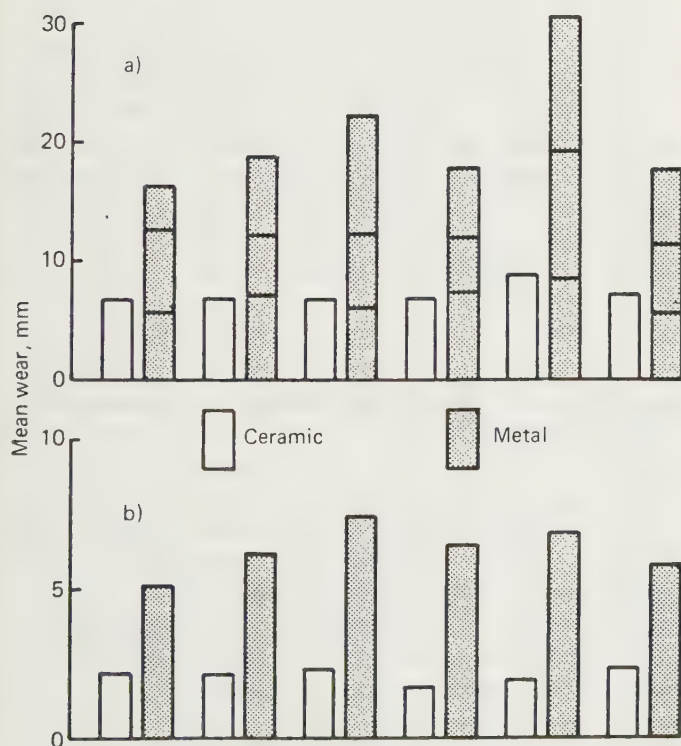


Fig. A4.1 Results of wear comparisons on root drill coulters, carried out by Silsoe Research Institute. (a) Hestair-Webb: all-metal V ceramic inserts on cutting edge of Suffolk type; all-metal replaced twice on 475 acres. (b) Hestair-Stanhay: all-metal V ceramic replaceable tips with no replacements on 355 acres. (*Silsoe Research Institute diagram*)

As with most other very hard materials, securing an improved life from components such as renewable cultivator points working in hard soils requires suitable construction methods, e.g. backing by tougher materials such as steel, to avoid fractures resulting from brittleness. Economic progress has been based mainly on designs using proprietary alumina ceramics with all-round steel backing. Results of extensive field trials of sugar beet drill coulters on very abrasive soils provide firm grounds for study of wider applications.

In co-operative work with a manufacturer of two drill types, alternate coulters of 12-row drills were fitted with steel coulters and ceramic-faced as follows: Hestair-Webb with integral ceramic insert in the main cutting edge of the Suffolk type coulters; Hestair-Stanhay with replaceable ceramic tips on the cutting nose of the general-purpose coulters. The wear comparisons are illustrated in Fig. A4.1. In the Webb drill, 475 acres of very abrasive flinty soil were drilled without change of coulters with ceramic inserts; three sets of all metal coulters were needed on the adjacent units. In the Stanhay comparison, wear rate of the metal tips was again three times as great; work continued without change of coulters on 355 acres, but the blunt points on the all-metal were increasingly unsatisfactory, and a result was that average plant emergence on the ceramic-coulter rows was 7% higher.

Cement and concrete

Cement is a pulverised material composed principally of silica, alumina and lime. When mixed with water, it undergoes a chemical change, forming new compounds which develop the property of setting into a solid mass. Concrete is a mixture of cement with a quantity of inert materials which, when mixed with water, will harden to form an artificial stone. Mortar is a mixture of cement, sand and water. In making concrete, the inert material may be sand, pebbles or broken stone, and the term applied to these materials is the *aggregate*. The aggregate should be clean, for impurities of an organic nature may prevent the mortar or cement from hardening and attaining its maximum strength. For concrete work where strength is required, it is generally desirable that the aggregate should be well assorted as to size of particles. The best aggregate contains just a sufficient number of smaller particles to fill the interstices between the larger ones, and the better this filling of spaces is achieved, the lower the proportion of cement required. Where great strength is required and cost is a minor consideration, a rich mixture should be used, but this condition rarely occurs in the use of concrete for farm work.

Typical mixtures for various types of work are:

Strong. 1 part cement; $1\frac{1}{2}$ parts sand; 3 parts coarse aggregate. This may be used for columns.

Standard. 1 cement; 2 sand; 4 coarse aggregate; used for reinforced floors, engine foundations and similar purposes.

Medium. 1 cement; $2\frac{1}{2}$ sand; 5 coarse aggregate; used for ordinary floors, foundations and walls.

Lean. 1 cement; 3 sand; 6 coarse aggregate; used in large masses for foundations and thick walls.

The importance of thorough mixing of concrete cannot be over-emphasised. Every grain of the aggregate must be coated with a film of cement if the maximum strength is to be achieved. The concrete should be used in a medium to wet condition where possible, but if mixed with only a minimum quantity of water, care must be taken to ensure that it is well rammed. It is generally stronger if used rather wet, but takes longer to set hard. It should be put in place within about 45 min of mixing, and should remain undisturbed for at least 10 hours.

Concrete has great strength in compression and is also fairly strong in shear, but it is rarely used in tension. In

reinforced structures, where tension must be considered, only the tensile strength of the reinforcement should be taken into account.

Timber

Wood is well adapted to resist shocks and vibration, and is sometimes used for machine parts receiving such treatment. It is strong for its weight, and has the great advantages of being easily fashioned by unskilled labour and also of being home-grown on many farms. A few of the hard and durable woods are used for special purposes in the construction of farm machinery, but mild steel is found on many modern machines where wood used to be employed. In spite of this, wood is still an important material in agriculture; trailer bodies, fences, gates and buildings are often almost entirely constructed of timber.

The quality of wood is determined to a large extent by the selection of the trees and the care used in cutting, seasoning and preserving. It only remains a reliable material, however, so long as it is preserved from decay. Seasoned timber kept indoors, free from contact with the ground, is generally too dry for the attack of fungi, but where conditions of moisture and temperature favour the growth of bacteria and fungi, wood that is not effectively protected may be attacked and destroyed. Some timbers, notably oak and larch, are naturally durable, while alder, beech, birch, ash, elm and Scots pine are undurable unless protected. Paint is the preservative mostly applied, but neither this nor tar is as good as impregnation with a proprietary fungicidal liquid or creosote for wood that is continually damp.

There are three main methods of treating timber with creosote, and the least satisfactory of these is the surface treatment achieved by brushing or dipping. The process widely employed by timber merchants is impregnation with hot creosote under pressure inside a sealed cylinder. This produces good results, but is hardly practicable on the farm. A method that can be recommended for the preservation of fencing material, etc., on the farm is the *open tank* method. The timber is placed in creosote in a suitable metal drum, and a fire kindled beneath. The temperature of the creosote should be raised to about 82–93°C in two hours. During this time, air and moisture are driven off from the timber. Cooling is then allowed to take place, and after about twenty-four hours the

timber is usually well impregnated. The cost of this method of preserving timber is trifling compared with the effects. Fortunately, sapwood and naturally undurable wood takes up the creosote very readily if the bark is peeled off.

Thermal insulation materials

Whenever it is necessary to control the temperature in a building – whether the object is to keep temperature low in a cold store, or to keep it high in a livestock building, it is necessary to restrict the flow of heat into or from the building by means of insulation. In stock buildings, good insulation enables warm conditions to be maintained in winter, and helps to prevent overheating in summer. It also helps to avoid condensation, and to keep the atmosphere and bedding dry.

Thermal insulation is achieved by the use of dead spaces provided by cavity walls, by means of heat reflective surfaces and by using materials of low thermal conductivity. The insulating properties of a material are indicated by its *K*-value. The *K*-value (Imperial units) is the heat loss (Btu per hour) through 1 ft² of the material, 1 in thick, per 1°F difference in temperature between the two surfaces. In SI units, *K*-values are in joules per second, i.e. watts, and the figures are for W/m m²°C. Wood, which is a poor insulator, has a *K*-value five times as great as glass wool, a good insulator.

In practice, materials are often not available in any desired thickness, and it is easier to specify the thermal conductivity of the materials as they can be bought or made up: e.g. a brick wall; a corrugated iron roof; or a roof of corrugated asbestos lined by polystyrene slabs. The insulating value of such materials is indicated by the *U*-value (thermal transmittance). The *U*-value (Imperial units) is the amount of heat (Btu per hour) that passes through 1 ft² of the particular form of construction when there is a difference in temperature of 1°F between the two sides. Thus, for a uniform material such as polystyrene, the *U*-value of a 2-in sheet is simply twice the *K*-value. In SI units, *U*-values are in joules per second, i.e. watts, and the figures are for W/m²°C. Typical *U*-values for some common materials used in farm building construction are given in Table A6.2. Uninsulated roofs, whether of corrugated iron or corrugated asbestos, are very poor insulators, but the addition of insulating boards

and a glass fibre quilt, or 25 mm thick (1 in) polystyrene, provides good insulation.

Most insulating materials rely on the maintenance of free air-space within them, and their effectiveness is seriously reduced if the material becomes saturated with moisture. In many types of building where it is necessary to insulate (e.g. pig and poultry houses) there is a warm, damp atmosphere inside the building, and it is often much colder outside. In these conditions there is a tendency for moisture to condense on the underside of the roof if the moisture is allowed to reach this point. In addition to reducing effectiveness of the insulation, it may cause it to rot. It is therefore advisable to provide on the inside of any porous insulating materials some kind of vapour barrier which prevents moisture condensing in the insulation. Some modern insulating materials, e.g. polystyrene slabs, have a specially prepared surface which itself provides a fairly good vapour barrier, especially if painted. When porous materials are used, a special vapour barrier such as aluminium foil or a good quality tarred building paper must be used as a continuous lining on the warmer side.

Paints

Paint is a material which, though liquid when applied, dries after application and forms a thin film that is comparatively hard. On ageing, it becomes gradually harder and more brittle, and eventually it fails. The length of life varies considerably, but there is no permanent paint. Factors influencing the ultimate breakdown are the composition of the paint, the surface to which it is applied and the weathering influences.

With both wood and metal equipment it is desirable to paint at once, while the surface is still new and clean, and before rust or cracks do irreparable damage. Wood, being a porous material, absorbs a good deal of paint, and needs three or four coats for full protection. It should be cleaned and wiped down smooth before painting with a primer (first coat).

Paint used for metal surfaces must possess certain distinctive characteristics, among which are rust prevention, distensibility, a high spreading rate, durability and ease of application. The primer must be one adapted to metal surfaces, for paints that are suitable for wood or are good

finishers may be of little use as primers for metal. Paints commonly used for metals include red lead, lead chromate, zinc oxide, metallic aluminium powder and metallic zinc powder. Bituminous paints are very suitable for painting metal surfaces which are exposed to the weather, e.g. metal roofing.

Since the cost of labour frequently exceeds that of the paint, it is generally advisable to use a high-grade paint, whether for wood or metal. Repainting should be carried out before failure is far advanced, for over a period of years, good paint applied at sufficiently frequent intervals is the cheapest.

Electricity on the Farm

Provision of a supply of electricity to a very high proportion of farms has paved the way for great improvements in efficiency of many aspects of farming. Electricity also brings the benefit of making farm work more attractive by the elimination of drudgery, and by providing essential amenities in the homes of farmers and farm workers.

Provision of a mains supply to distant farms is, of course, expensive. Even for ordinary rural distribution networks, expenditure on cables, etc., can represent as much as 75% of the total cost of the supply. As the use of electricity on farms increases, distribution networks have to be reinforced; where there is a considerable demand for motive power, changes from single-phase to three-phase supplies become increasingly desirable.

As is more fully explained later, electricity for most purposes must be available at a low voltage, e.g. 240 volts; but it is impossible to transmit power economically for long distances at low voltages, and the high-voltage lines now a common sight in rural areas convey it at 132 000, 66 000, 33 000 or, for shorter distances, 11 000 volts. The transforming of power from high voltages to low requires expensive apparatus, and it is uneconomic to 'tap' lines of 66 000 or 33 000 volts for the supply of isolated farms. It is, however, quite common to tap 11 000-volt lines, the cost depending to some extent on the amount of power required.

Applications of electricity

Except for certain specialised applications such as electro-culture, electric fences, etc., electricity is used on farms for carrying out quite orthodox processes where heating, lighting and power devices are concerned. The general conditions applying in each case are dealt with in the appropriate chapters, and only those particular principles peculiar to electrical operation are dealt with here.

Lighting

The advantages of electric lighting in farm buildings, especially where dairying is carried on, are so obvious as to render detailed description unnecessary.

Special uses on farms include artificial lighting for laying hens during winter. With well-managed flocks it is found economic to extend the day to 12–14 hours by providing light both in the morning and evening. A great deal has been learned, by means of controlled experiments, concerning the optimum lighting regime for hens at various stages of their production cycle. For highest efficiency, lighting programmes must be carefully integrated with many other factors, notably feeding and temperature control.

Electric lighting has also been found suitable for stimulating the right kind of plant growth. For example, mercury vapour lighting is now widely employed in commercial glasshouses for illuminating tomato and cucumber seedlings, and this results in earlier crops.

For the production of glasshouse flower crops such as carnations and all-the-year round chrysanthemums, it is necessary to provide strictly controlled lighting treatments; in practice this involves some use of blackout materials to prevent light reaching the plant during part of the day. Knowledge concerning these lighting effects is well documented and careful attention to detail is essential for commercial success in flower production.

Another special use of electric lighting is in potato chitting houses, where fluorescent tubes are employed to induce short green sprouts. A well-insulated barn with sufficient tubes to provide the necessary light requires little extra heat even in the coldest weather normally experienced in Britain. There is, therefore, a considerable saving in fuel compared with use of a glass chitting house.

The light is best supplied by 'warm-white' fluorescent tubes, which are suspended in a vertical position from

straining wires, rods or a sliding door track in such a way that the light tubes can be easily moved along the alleyways between the rows of trays. As a general rule, one set of lights is provided for about eight stacks of trays, four on each side of the alleyway; each set of tubes is regularly moved in succession to a position opposite each pair of trays in turn. Special lights 8 or 10 ft long, complete with capacitor, choke and starter unit, are available. Other lengths can be made up from a number of standard 1.2 m (4 ft) tubes, but may be more expensive. All light units should be properly earthed, and the equipment should be installed by a qualified electrician.

Though light is necessary for production of green sprouts, it is mainly temperature that controls the beginning of sprouting and the rate of growth; it is advisable to provide a good degree of thermal insulation, not only to protect against frost, but also to prevent the development of high temperatures in the chitting house in a warm spring. Good ventilation is also necessary, in order to even up temperatures and sometimes to carry out some cooling when outside conditions permit. A 3 kW heater with a 230 mm (9 in) fan is usually provided for about every 10–15 tons, the heater being automatically switched on if the temperature falls to near freezing point.

Heating

Practicable heating is produced by so designing apparatus as to concentrate in a comparatively limited space the dissipation of the appropriate amount of electrical energy. This heat may appear as 'radiant' and visible heat as in an electric fire or radiator, or as 'dark' heat as in the enclosed tubular heater. Apart from the psychological effect of the luminous bars and certain minor physical differences, the heating effect is similar from whatever source. The main criterion is the number of kW used per hour, remembering that every kWh produces 3590 kJ (3400 Btu).

The drawback to electrical heating is, of course, that it tends to be expensive compared with coal or oil, in terms of cost per unit of heat produced. Why, therefore, is electricity used at all for heating? First because a straight 'heat units' comparison is not the whole story, since, while the conversion of the electrical energy into heat is possible at something approaching 100% efficiency, conversion of the energy of solid fuel or oil into heat when it is required is, in practice, probably rarely done at an

efficiency higher than 33 $\frac{1}{3}$ %. This still leaves a gap which is met by the operational advantages of electricity – advantages on which it is difficult to place any money assessment, but which are of some considerable value.

These operational advantages are briefly as follows:

Cleanliness: an electrical steriliser can be placed in the milk room without any fear of creating dirt.

Appositeness: the heat can be applied where it is wanted; this is a valuable point in heating chicken brooders.

Controllability: automatic control on either time or temperature basis is readily provided.

Labour saving: possibly the most important single factor.

Both radiant heat and dark heat methods are employed in the heating of chicken rearers. One type of brooder has a cluster of carbon-filament lamps to provide the heat; another type employs a dull red heat produced by a heating element of the usual type; while a third employs elements of the tubular dark-heating type.

Similar heater units may be employed for warming other kinds of livestock. An alternative method of applying heat in farrowing pens is to locate warming elements of very low voltage in the floor of the pen. One simple method of installation is to build the warmed floor section above the original floor of the pen. A layer of dry sand 38 mm (1 $\frac{1}{2}$ in) thick is first spread on the section to be heated, and a sheet of corrugated asbestos shuffled into it until it is firmly bedded, with no air spaces beneath. The upper troughs of the asbestos are then half-filled with sand, the wires of the heater element laid in the troughs, and more sand added. Then a sheet of expanded metal is laid on top of the sand and the whole covered with 37.5 mm (1 $\frac{1}{2}$ in) of concrete. The wires of the heater element are connected to a transformer which produces a very low voltage. In cold weather such an installation results in fewer piglet losses and an increase in growth rate. More recently, floor warming has been successfully used for rearing chicks, for heating mushroom houses and for warming the feet of operators in packing sheds. The method of construction for poultry houses is generally as shown in Fig. A5.1. The heating cables are of an electrically insulated mains voltage type, and are usually laid directly in a thermally insulated mass of concrete, at a depth of about 150 mm (6 in) from the surface. Current is generally supplied at off-peak periods, so that the efficiently applied heat of the 'Floor-store' can compete

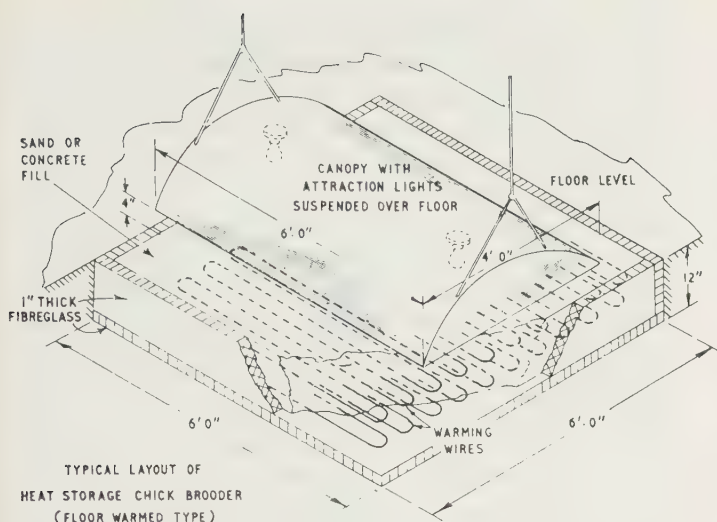


Fig. A5.1 General arrangement of electrical floor-warming installation for poultry rearing.

in cost with other forms of heating. Details of construction and typical capital and operating costs are given in an Electricity Council publication.

The heating effect of electricity is seen to great advantage in running such devices as incubators, which use very little power when once the correct temperature has been reached.

Where heat is required in very large amounts, such as in soil heating or crop drying, electricity can only compete with other sources of heat if power is obtained at a cheap rate. Improvements are, however, continually being made in such matters as the proper insulation of hotbeds and the design of grain driers for all-electric operation.

Soil warming is applied to the heating of hotbeds, propagating beds and benches, and to beds and borders in glasshouses. For these purposes the 'dosage' method is generally employed in preference to methods involving thermostatic control. By the dosage method, whereby the soil is warmed for a limited period each day, soil temperature may fluctuate considerably, but this does not appear to affect growth adversely unless the temperature falls to near freezing point.

The whole subject of heating by electricity needs to be viewed with an open mind, remembering the special advantages already mentioned.

Power: single-phase and three-phase

Electricity may be used to provide motive power in either single-phase or three-phase form. Single-phase is the simple form, analogous to direct current and requiring only two wires to provide the supply. Three-phase is an ingenious development from the basic single-phase and may be regarded as a superimposing of three single-phase systems to form one system. Its main value consists in the fact that these three systems can be carried on three conductors and not on three pairs of conductors as might be expected. This results in a substantial economy in the cost of supply lines, and the system is used for all main transmission and much secondary transmission line. When, however, we come to small lines and comparatively small loads, such as are found in rural areas, it is often cheaper to use a pair of conductors supplying single-phase only. One fortunate fact is that single-phase, which is required for lighting, small power and domestic applications, can be taken from a three-phase system.

In the past there has been some prejudice against single-phase motors, but any justification for this has long since disappeared. It is, however, true that the three-phase motor has a better starting torque, so that for given duties the single-phase has always to be of a more advanced type. This results, too, in the single-phase motor always being dearer for a given duty, although the extra cost is largely due to the more complicated starting equipment required to reduce the starting current for the single-phase motor.

AC electric motors offer the most simple and most robust type of motive power unit available to farmers. An AC motor of good make should last a generation without anything other than ordinary running attention. The simplest and most robust of all types is the three-phase squirrel cage motor which has no connections at all to the moving part. This type is permissible in practically all three-phase supplying areas up to 2.25 kW (3 hp), but because of the higher starting current some area boards ban it above this, and few allow it above 7.5 kW (10 hp). These bans are generally lifted if special types of starter are fitted. In any case, if the squirrel cage motor is banned, the slip-ring type can be used, but this costs more.

These various restrictions are not imposed arbitrarily nor merely to make farmers spend money unnecessarily. They are devised for the common good, since the im-

sition of high starting loads would interfere with the general supply, possibly causing lights to dim, while in certain cases of sensitive protective gear other people's motors would stop. (This sort of thing happens in the rural supply systems of some foreign countries where no such scheme for the common good has been enforced.)

The speed of the ordinary commercial type of AC motor depends on the frequency of the system (50 cycles per second in this country) and is related to it. Motors have, therefore, the following synchronous speeds: 3000 rpm, 1500 rpm, 1000 rpm, 750 rpm, 500 rpm. The actual speed at full loads will be 2800 rpm, 1480 rpm, 960 rpm, 710 rpm, 450 rpm respectively, being rather higher at part loads.

There have been attempts in the past to make a case for special 'farm motors'. Experience has shown, however,

that there is no condition on the farm which cannot be met by a standard industrial motor of some type. Indeed, there is little need on the farm for any other than the ordinary protected type of motor, even for dusty situations. Farm dust is not usually abrasive or corrosive, and there is rarely any trouble from this source.

A special type of motor is, naturally, required for such specialised work as use in connection with the submersible centrifugal pump. It is also necessary to choose a totally enclosed type where constant splashing by liquid, especially by an acid, is expected.

Automatic controls

One of the most useful characteristics of electric power is the ease with which automatic control can be contrived.

Fig. A5.2 Simple switches for automatic control. (*Alvan Blanch*)

Left: Pressure switch for use in sides of large chutes or hoppers.

Right: Probe-switch for use in hopper outlets through which granular materials flow.



This is generally on a quantity basis or on a time basis, and if required can be on a rate basis, a humidity basis or on a temperature basis. It is this quality which has allowed the development of the low-loaded hammer mill, controlled automatically by the amount of grain which has passed through and by the time of using to grind a required quantity. Pressure control is used for automatic water supply in the pressure-tank system, and height control when the gravity-tank system is used. Humidity is used to control grain drying in bulk grain stores, and to control cooling in bulk dried grain stores and many other types of crop storage, notably of root vegetables and potatoes.

Other simple electronic controls now widely used in agriculture include:

Solids flow, acoustic switch sensor: This may be used in any conveying application where movement of particles such as grain is involved. A small probe is located in a position where the conveyed material strikes it or flows round it. The sensor may be in the head or boot of an elevator or in the trunking of other types of conveyor. The acoustic signal can be used to set in motion relays that switch off all the major items in a complex installation in the event of failure of one of the conveyors. This protects the plant against a major breakdown.

Magnetic rotating shaft-monitor: The sensor has an inbuilt magnetic field and a coil loaded with a soft iron pole-piece. The sensor is located within 3.5 mm of the rotating member which may be a gear-wheel, sprocket, disc with protruding studs etc. The movement of the teeth etc. past the sensor alters the magnetic field and produces a change of voltage, which can be employed to monitor the movement. It is used to provide a warning or to switch off machinery if the speed falls to a preset level. A delay can be built into the switch system if required.

Thermal sensors: These may be used to initiate cooling by fan in a bulk grain drier or potato store, or to operate change-over air control valves in stores where there is a choice between drawing in atmospheric air or recirculation of the air already in the store: this is a common need for potato chitting stores or for stores holding bulk boxed potatoes, to avoid introducing air below freezing point.

Specialist firms manufacture installations to suit the requirements of individual stores, drawing on components from other manufacturers as needed.

Microprocessors

The scope of automation has been vastly enlarged by the availability of microprocessors. In the past, the automatic actions possible following receipt of a signal from a sensor have been simple, e.g. sounding a warning; switching on a red light; or breaking an electrical circuit. The advent of microprocessors greatly increases the number of practical options and will inevitably lead to an increasing degree of refinement in responses. Already cooling and recirculation package units are available (e.g. Chandler Farm Electronics and Installations) which provide 'zone control', to ensure that the ventilating air is directed to the zone where it is shown to be needed by the temperature sensor installed in that zone.

Reference is made in other chapters to the use of microprocessors to increase efficiency of control of various agricultural machines. Such developments justify mention again not to review trends in detail but as a reminder that a high proportion of farm machines and processes could be involved before the end of the century. The remarkable progress already made in feeding and milking livestock, spraying, harvesting grain crops, planting potatoes, improving automatic controls on other self-propelled harvesters and technical processes makes it clear that only economic factors will decide the rate of changes.

Load characteristics

Farmers are sometimes puzzled by the insistence of supply companies on keeping down the size of motors. This arises from the fact that an electricity supply system has to be built to supply the largest simultaneous demand which may arise, although this may be in effect for perhaps only 30 minutes in the whole year. This maximum demand is, of course, governed by the size of the individual motors, etc., which may happen to be on simultaneously. If the number of large motors on the system is small, there is less chance of their simultaneous switching on being serious.

In the long run an improvement in the ratio of units consumed to maximum demand can help to avoid or delay tariff increases. Installation of a few big motors may result in additions having to be made to the supply system. A farm might be supplied through a single transformer of, say, 50 kW; but using, say, a 37.5 kW (50 hp)

and a 19 kW (25 hp) motor simultaneously would call for a larger and more expensive transformer. Looking at the matter nationally, it is for the common good to keep down the maximum demand.

As an example of what can be done, in the case of hammer mills, it is better from many points of view to have a 2.2 kW (3 hp) motor working for 10 hours rather than a 22.5 kW (30 hp) one working for one hour. Practical experience has proved that an automatic feed, delivery and control are eminently practicable. The fact that a 3 hp mill can grind grain at only a fraction of the speed of the large mill is met by making arrangements for the small mill to run quite unattended and to stop when the required amount of grinding is done.

Wiring

The wiring of farm buildings provides problems distinct from those arising in wiring houses, owing to the special conditions such as damp, fumes, shocks and extremes of temperature to which the installation may be subject. Distribution from the main switchboard to various buildings may be by overhead insulated cables supported by a catenary steel wire, or by underground insulated cables of armoured PVC. Since a minimum height of 5.8 m (19 ft) above roads is necessary, underground cable is generally preferable now that a suitable inexpensive type is available. Where the cable has to be laid a long distance, a mole plough can be used to place it in the soil. For use within buildings, many types of wiring are available, including various types of conduit tubing, metal-sheathed cable, rubber-sheathed cable, etc. The system most generally suited to farming needs is a part-insulated one, in which metal is not used for protection of the cables, but any essential metal parts such as the switch-gear are earthed. The most suitable types of insulated cable include PCP (polychloroprene), PVC (polyvinyl chloride) and TRS (tough rubber sheathed). An attractive alternative for some situations is the use of plastic conduit. Whatever the system, care must be taken in installing it, for badly executed work may be dangerous as well as inefficient.

Choice of wiring should depend primarily on ease and security of fixing, and this depends chiefly on the nature of the building. Where PVC or PCP can be adequately fixed, as on brickwork or solid timber, the sheathed cable alone is satisfactory, PCP being chosen where its

advantages of considerable strength and resistance to acids, etc., justify the slight extra cost. Sheathed cables can be further protected by plastic conduit in those places where mechanical damage is likely. Use of plastic conduit throughout is preferable in buildings where fixing is difficult, as on steel or concrete. In some large modern buildings, a grid suspension catenary system may be used. All electric circuits should be protected from the effects of overloading by the use of fuses. A fuse is a simple safety device generally consisting of a short length of wire which forms part of the electric circuit and is placed in a readily accessible position. The passage of a current through the wire causes the temperature to rise, the rise in temperature being proportional to the resistance and to the current flowing. The fuse wire must be so chosen that when too heavy a current passes through, it melts and automatically breaks the circuit. This type of fuse, with its rather clumsy method of re-setting, is gradually being superseded by small automatic circuit-breakers, which can be easily reset.

Electric generating sets

Efficient small diesel-electric generating sets are available for the production of a private electricity supply in isolated districts that cannot be reached by public supplies. Where such outfits are installed the main reason is usually a demand for lighting for domestic purposes.

When a generating set is being chosen, it is advisable to adhere to equipment which provides 230–250 volts AC, so that standard types of machines can be employed, and no changes in wiring or machines will be needed if a mains supply is later obtained. Linkage-mounted pto-driven generators are available to provide for an emergency supply of power and light. A reliable plant can be a worthwhile insurance on many holdings where electricity is essential for operation of vital equipment. This applies particularly to large-scale dairying and glasshouse crop production.

Where a permanent 'stand-by' source of electric power is required the best source is usually an alternator mounted on fixed rails inside a building, with tractor pto-drive through an exterior wall (Fig. A5.3). Advanced designs provide features such as ability to take care of high surges of power need when motors are started, and anti-condensation heaters to avoid problems caused by lack of use for long periods. Power provided can range from 10

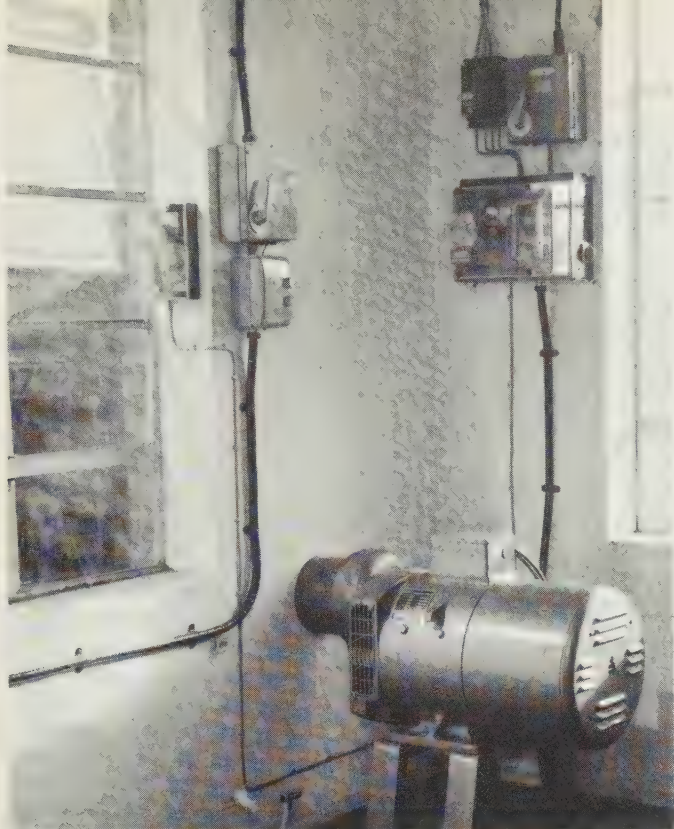


Fig. A5.3 Tractor-driven 'stand-by' generator. (Froment)

to 50 or 75 kW; so if a suitable tractor is available it is possible to cater for the whole range of operations involved in many fixed stock-feeding systems, as well as the vital tasks such as milking or powering an oil-fired glasshouse heating system.

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- Essentials of Farm Lighting*. Handbook No. 25. EC 3518. Electricity Council.
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Definitions and Useful Data

Definitions below include a few technical terms and relationships not specially concerned with agricultural machinery. A list of useful approximate metric conversions is given in Table A6.3.

The SI unit of force is the newton (N) defined as that force acting on a mass of 1 kg which produces an acceleration of 1 m/s^2 .

$$1 \text{ N} = 1 \text{ kgm/s}^2$$

Work, power and horsepower

In a technical sense, *work* has a restricted meaning. It is force acting through distance and representing a definite expenditure of energy. If the force is constant, the work done is measured by the product of the force and the distance through which the body moves in the direction of action of the force. The SI unit of work, comparable with the Imperial foot-pound, is the *joule*.

$$1 \text{ joule} = 1 \text{ newton-metre}$$

Power is the *rate* of doing work, or the amount of work done in a given time. The SI unit of power is the watt.

$$1 \text{ watt} = 1 \text{ joule/s} = 1 \text{ Nm/s}$$

(The Imperial unit of power, the horsepower, determined by James Watt in 1780 as a result of experiments with horses, is 33 000 ft lb/min).

$$1 \text{ hp (Imperial)} = 746 \text{ watts}$$

All energy quantities are related; e.g. one joule of heat energy is equivalent to one joule of mechanical energy. More useful heat units are kJ, MJ.

Although energy cannot be destroyed, its conversion from one form to another always involves some wastage.

In the conversion of the energy of coal into mechanical energy in the steam engine, for example, about 85% of the heat energy in the coal is wasted and only 15% converted into work. Internal combustion engines can generally convert only about 20–30% of the potential energy of the fuel into useful work.

Definitions

Trailed implement: pulled and guided from a single hitch point; never completely supported by power unit.

Semi-mounted implement: attached to tractor at more than one point; responds directly to tractor steering; partly supported by tractor when out of work.

Mounted implement: completely supported by tractor when in the raised position.

Self-propelled machine: one in which the propelling unit is an integral part of the machine.

Field capacity of implements

Theoretical field capacity: rate of work that would be achieved if machine were performing its function at full rated forward speed for 100% of the time.

Effective field capacity: actual average rate of work, usually expressed in acres (or ha) per hour.

$$\text{Field efficiency} = \frac{\text{Effective field capacity}}{\text{Theoretical field capacity}} \times 100\%$$

Field efficiency varies with type of machine. Typical figures are: tillage, 75–90%; drilling, 70–85%; combine harvesting, 60–75%.

Assuming a fairly high average field efficiency of 82.5%, the capacity of a field machine, in acres per 10-hour day, is given by speed (mph) $\times$ working width (ft).

of life for different types of equipment need to be related to seasonal use. Tractor life is generally best estimated at 10 000 to 12 500 hours.

Useful life, depreciation and repair costs

For most practical purposes the useful life of equipment can be estimated at from 5 to 12 years. Specific estimates

Operating speeds

Table A6.1 summarises operating speeds generally suitable for common farming operations.

Table A6.1

Operation	Ground speed											
	km/h mph	0.8 0.5	1.6 1	2.4 1.5	3.2 2	4 2.5	4.8 3	6.4 4	8 5	9.6 6	13 8	16–24 10–15
Transplanting	—	—	—	—	—	—	—	—	—	—	—	—
Mole draining	—	—	—	—	—	—	—	—	—	—	—	—
Potato harvesting	—	—	—	—	—	—	—	—	—	—	—	—
Potato planting	—	—	—	—	—	—	—	—	—	—	—	—
Potato digging	—	—	—	—	—	—	—	—	—	—	—	—
Root drilling	—	—	—	—	—	—	—	—	—	—	—	—
Root hoeing	—	—	—	—	—	—	—	—	—	—	—	—
Beet harvesting	—	—	—	—	—	—	—	—	—	—	—	—
Rotary cultivating	—	—	—	—	—	—	—	—	—	—	—	—
Ploughing	—	—	—	—	—	—	—	—	—	—	—	—
Cultivating	—	—	—	—	—	—	—	—	—	—	—	—
Disc harrowing	—	—	—	—	—	—	—	—	—	—	—	—
High-speed draught seedbed implements	—	—	—	—	—	—	—	—	—	—	—	—
Ridging or splitting	—	—	—	—	—	—	—	—	—	—	—	—
Manure spreading	—	—	—	—	—	—	—	—	—	—	—	—
Fertiliser distributing	—	—	—	—	—	—	—	—	—	—	—	—
Grain drilling	—	—	—	—	—	—	—	—	—	—	—	—
Combine harvesting	—	—	—	—	—	—	—	—	—	—	—	—
Fruit spraying	—	—	—	—	—	—	—	—	—	—	—	—
Field crop spraying	—	—	—	—	—	—	—	—	—	—	—	—
Mowing	—	—	—	—	—	—	—	—	—	—	—	—
Forage harvesting	—	—	—	—	—	—	—	—	—	—	—	—
Tedding or turning	—	—	—	—	—	—	—	—	—	—	—	—
Road haulage	—	—	—	—	—	—	—	—	—	—	—	—

Farm Machinery

Thermal transmittance

Table A6.2 gives a list of *U*-values for some materials commonly used in farm building construction.

Table A6.2 *U*-values (thermal transmittance, W/m²°C)

ROOFS	<i>U</i> -value	WALLS (<i>contd.</i>)	<i>U</i> -value
Corrugated steel sheeting	8.5	75 mm (3 in) clinker breeze blocks, cement rendered outside	2.38
Corrugated asbestos sheeting	7.95	225 × 225 × 450 mm (9 in × 9 in × 18 in) hollow clinker concrete blocks cement rendered outside	1.82
Corrugated asbestos lined with 12.5 mm ($\frac{1}{2}$ in) boards	2.04	75 mm (3 in) clinker breeze blocks, cement rendered outside and lined with 225 mm (1 in) fibre board	0.96
Corrugated asbestos lined with 25 mm (1 in) polystyrene slabs	1.02	WINDOWS	
Corrugated asbestos pitched roof with ceiling of wire mesh, building paper, and 25 mm (1 in) glass fibre mat	1.14	Single-glazed windows	5.68
Corrugated steel sheeting with 25 mm (1 in) glass fibre mat fixed above purlins	1.19	Double-glazed windows, 3 mm ($\frac{1}{8}$ in) air space	4.26
Double aluminium with glass fibre infill	0.68	Double-glazed windows 19 mm ($\frac{3}{4}$ in) air space	3.12
Corrugated asbestos and 300 mm (12 in) straw	0.57	FLOORS	
WALLS		Dense solid concrete laid on ground with four exposed edges.	
112 mm ($4\frac{1}{2}$ in) brickwork	3.63	7.6 m × 7.6 m (25 ft × 25 ft)	0.74
150 mm (6 in) dense concrete	3.41	15.3 m × 7.6 m (50 ft × 25 ft)	0.63
225 mm (9 in) brickwork	2.67	15.3 m × 15.3 m (50 ft × 50 ft)	0.45
280 mm (11 in) cavity brickwork	1.70		
355 mm (14 in) solid brickwork	1.70		

Table A6.3 Approximate metric conversions

	Metric/SI units		Imperial units	
LENGTH	25.4 mm	millimetre	inch	1 in
	0.3048 m	metre	foot	1 ft
	0.9144 m	metre	yard	1 yd
	1.609 km	kilometre	mile	1 mile
AREA	645 mm ²	square millimetre	square inch	1 in ²
	0.09 m ²	square metre	square foot	1 ft ²
	0.84 m ²	square metre	square yard	1 yd ²
	0.4047 ha	hectare	acre	1 acre
VOLUME	28.3 dm ³	cubic decimetre	cubic foot	1 ft ³
	0.76 m ³	cubic metre	cubic yard	1 yd ³
	4.55 l	litre	gallon	1 gal
MASS	0.454 kg	kilogram	pound	1 lb
	50.8 kg	kilogram	hundredweight	1 cwt
	1016 kg	kilogram	ton	1 ton
	1.016 t	tonne		
VELOCITY	0.0051 m/s	metres/second	feet/minute	1 ft/min
	1.61 km/h	kilometres/hour	miles/hour	1 mph
FLOW RATE	8.4×10^{-5} m ³ /s	cubic metres/second	cubic feet/minute	1 ft ³ /min
FORCE	4.448 N	newton	pounds force	1 lbf
PRESSURE	0.06895 bar	bar	pounds force/ square inch	1 lbf/in ² (1 psi)
	0.07 kg/cm ²	kilograms/square centimetre	inch mercury	1 in Hg
	33.86 mbar	millibar	inch watergauge	1 in wg
	2.5 mbar	millibar		
POWER	0.746 kW	kilowatt	horsepower	1 hp
RATE OF USE	2510.7 kg/ha	kilograms/hectare	tons/acre	1 ton/ac
	125.5 kg/ha	kilograms/hectare	hundredweight/acre	1 cwt/ac
	254 m ³ /ha	cubic metres/hectare	acre-inch	1 acre-inch
	11.2 l/ha	litres/hectare	gallons/acre	1 gal/ac
	1.25 kg/ha	kilograms/hectare	nutrient rate	1 unit/ac
HEAT, INSULATION, VENTILATION	1.055 kJ	kilojoule	British thermal unit	1 Btu
	4.1868 J	joule	calorie	1 cal
U-VALUE (THERMAL TRANSMITTANCE)	5.678 J/m ² s°C = 5.678 W/m ² °C		1 Btu/ft ² h°F	
K-VALUE	0.144 W/m ² °C		1 Btu/in ft ² h°F	
SPECIFIC HEAT	4.187 kJ/kg°C		1 Btu/lb°F	
CALORIFIC VALUE	3.73×10^{-8} J/m ³		1 Btu/ft ³	
	2.32 kJ/kg		1 Btu/lb	

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Table A6.4 Approx. bushel weight etc. of common crops

	Wt. per bushel (lb)	Volume per ton	
		(ft ³)	(m ³)
Wheat	63	46	1.30
Oats	42	70	1.98
Barley	56	51	1.45
Rye	57	51	1.45
Peas	63	46	1.30
Beans	66	43	1.22
Potatoes	50	54	1.53

British Standards

BS 1841: 1973	<i>Attachment of mounted implements to agricultural wheeled tractors</i>
BS 2468: 1963	Part 2: Metric (= ISO 730) <i>Glossary of terms relating to agricultural machinery and implements</i>
BS 2632: 1980, 1986	<i>Mains-operated electric fence controllers</i>
BS 2917: 1977	<i>Graphical symbols for use in diagrams for hydraulic and pneumatic systems</i> (= ISO 1219)
BS 2947: 1985	<i>Steel roller chains and chain wheels</i> (= ISO 487)
BS 3417:	Part 1: 1984 <i>Power take-off drive shafts</i> Part 2: 1984 <i>Methods for testing guards</i> Part 3: 1986 <i>Supplementary requirements to Part 1 and Part 2</i>
BS 3486	<i>Wheels for agricultural machinery, implements and trailers</i> Part 1: 1962 <i>Wheel and hub centre dimensions</i> Part 2: 1970 <i>Tyre and rim sizes</i> Part 3: 1970 <i>Nuts</i>
BS 3543	<i>Baler twines</i> Part 1: 1972, 1978 <i>Sisal</i> Part 2: 1980 <i>Polyolefin</i> (= ISO 4167)
BS 3733: 1974	<i>Endless V-belt drives</i> (= ISO 3410)

BS 3986: 1966

BS 4026

BS 4063: 1973

BS 4115

BS 4220

BS 4286

BS 4409

BS 4639: 1987

BS 4742

Methods of test for agricultural grain driers
Rod links for root machinery
Part 3: 1969, 1983 *Potato elevator diggers and main elevators on complete potato harvesters*
Part 4: 1969, 1983 *Carrot and sugar beet harvesters*
Requirements and testing of protective cabs and frames for agricultural wheeled tractors (Dynamic)
Compression knapsack sprayers
Part 1: 1967 *Non-pressure retaining type*
Methods of test for seats on agricultural wheeled tractors
Part 1: 1974 *Tests on artificial track*
Steel ducting for grain and fodder conveying
Part 2: 1981 (Metric units)
Screw conveyors
Part 2: 1970 *Portable and mobile augers for agricultural and light industrial use*
(= ISO 1050, 1819)
Brakes and braking systems for towed agricultural vehicles
Hydraulic equipment for agricultural machinery
Part 2: 1983 *Couplers*
(= ISO 5675)
Part 3: 1985 *Dimensions and pressure rating for single-acting telescopic tipping cylinders for trailers*
(= ISO 5670)
Part 4: 1985 *Hydraulic couplings on braking systems for trailers and trailed equipment*
(= ISO 5676)
Part 5: 1985 *Dimensions of braking cylinders for trailers and trailed equipment*
(= ISO 5669)
Part 6: 1988 *Dimensions and*

- location of agricultural tractor hydraulic return to sump porting
Part 7: 1989 Port connections for agricultural trailed vehicle hydraulic brake couplings
Part 8: 1990 Colour coding of remote hydraulic power services and controls on agricultural tractors
- BS 4746: 1971 Recommendations for the location and direction of movement of controls of pedestrian-operated tractors, agricultural and horticultural machines
- BS 4964 Symbols for control markings and displays
Part 1: 1981 Common Symbols (= ISO 3767)
Part 2: 1981 Agricultural tractors and machines (= ISO 3767)
- BS 5137: 1974, 1983 Requirements for the compatible operation of forage harvesting machinery
- BS 5389: 1976 Tests for enclosure pressurisation systems on tractors and self-propelled machines
(= ISO 3737)
- BS 5401: 1990 Guide to information content and presentation of operators' manuals provided for tractors and machinery for agriculture and forestry
- BS 5453: 1977 Anchorages for seat belts in cabs and frames on agricultural tractors
(= ISO 3776)
- BS 5510: 1977 Maximum travel speed determination (= ISO 3965)
- BS 5731 Apertures and mountings for controls for operation of external equipment from protective cabs
Part 1: 1979 Apertures
- BS 5802: 1979 Maximum actuating forces for tractor controls
- BS 5822: 1979, 1987 Agricultural discs
- BS 5861: 1980 Rear power take-offs on agricultural tractors (= ISO 500)
- BS 5891: 1980 Ring type hitches on agricultural trailers and towed implements
(= ISO 5692)
- BS 5947: 1980, 1985 Static loading test and acceptance conditions for protective cabs and frames for agricultural wheeled tractors
- BS 6055: 1981, 1987 Measurement of whole-body vibration of the operators of agricultural wheeled tractors and machinery
- BS 6108: 1981 Dimensions of hook type couplings on agricultural towing vehicles (= ISO 6489/1)
- BS 6142: 1981 Presentation of technical data on hydraulic systems (= ISO 5676)
- BS 6347 Performance assessments of agricultural tractors
Part 1: 1983 Available power (= ISO 789/1)
Part 2: 1983, 1989 Hydraulic power and lift capacity
(= ISO 789/2)
Part 3: 1983, 1989 Turning circle and clearance (= ISO 789/3)
Part 6: 1983, 1989 Centre of gravity determination
(= ISO 789/6)
- BS 6355: 1983 Equipment for crop protection: glossary (= ISO 5681)
- BS 6356: Spraying equipment for crop protection
Part 1: 1983 Sprayer nozzles: methods of test (= ISO 5682/1)
Part 2: 1985 Connecting dimensions for nozzles and manometers (= ISO 8169)
Part 3: 1985 Dimensions of connection threading
(= ISO 4102)
Part 4: 1989 Performance limits for field spraying nozzles
- BS 6369: 1983 Battery-operated electric fence controllers suitable for connection to supply mains
- BS 6384: 1983, 1989 Determination of braking performance of agricultural and forestry vehicles (= ISO 5697)

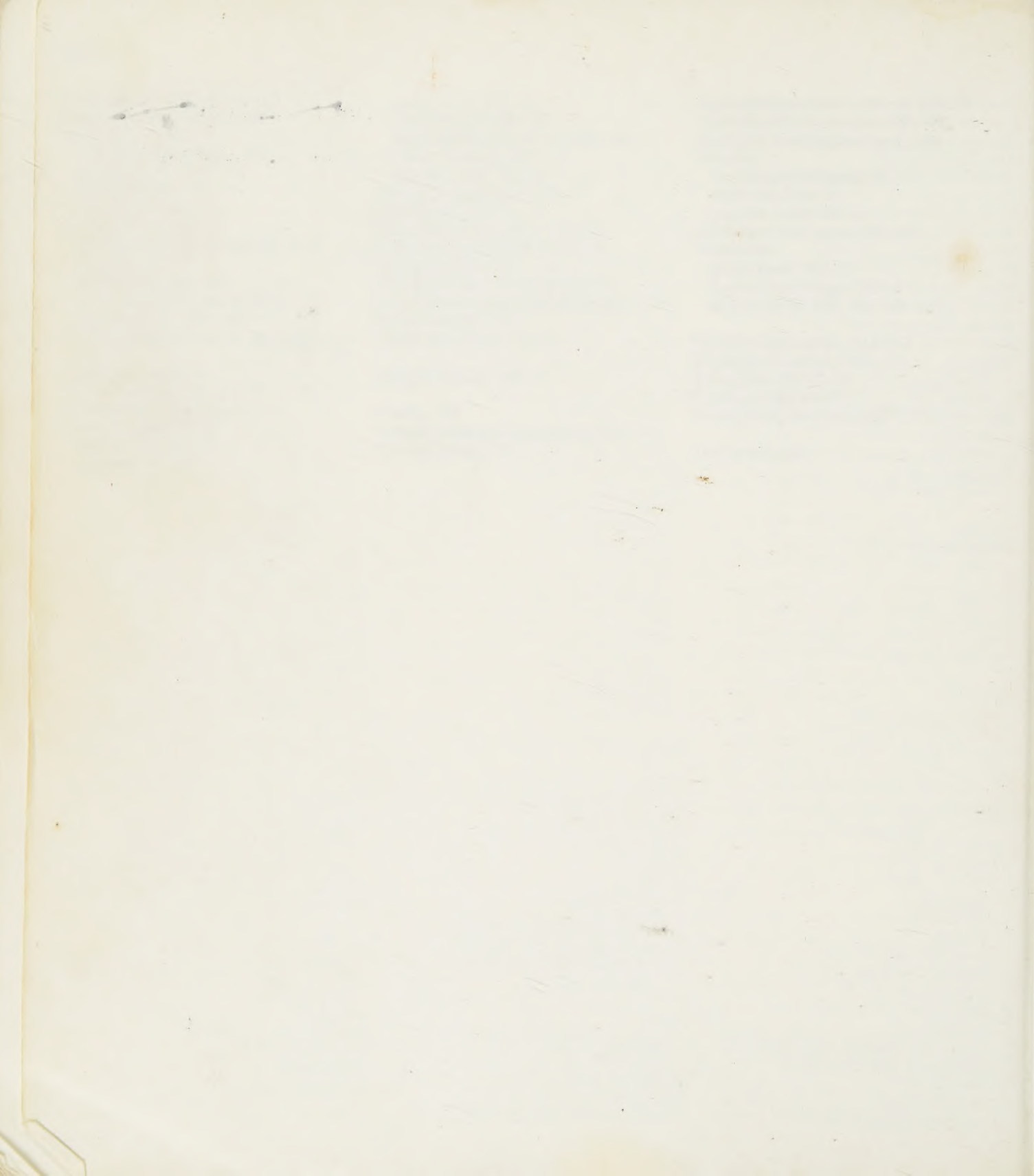
	<i>Determination of operator's field of vision for agricultural tractors (= ISO 5721)</i>	BS 6792: 1986	<i>Agricultural trailer and trailed machinery drawbar jacks</i>
	<i>Fertilizer distributors</i>	BS 6818	<i>Front-mounted linkage and power take-off for agricultural wheeled tractors</i>
	<i>Part 1: 1984 Evaluating performance under laboratory and field conditions (= ISO 5690/1)</i>		<i>Part 1: 1987 Power take-off (= ISO 8759/1)</i>
	<i>Part 2: 1985 Test for fertilizer distributors in lines (= ISO 5690/2)</i>	BS 6978	<i>Part 2: 1987 Front linkage (= ISO 8759/2)</i>
BS 6508: 1984	<i>Recommendations for preferred track widths for agricultural tractors and machinery (= ISO 4004)</i>		<i>Seed drills</i>
			<i>Part 1: 1988 Test for single seed drills (= ISO 7256)</i>
BS 6509: 1984	<i>Clearance zone on implements for 3-point linkage attachment (= ISO 2332)</i>	BS 7006: 1989	<i>Part 2: 1990 Tests for seed drills for rows (= ISO 7256/2)</i>
		BS 7293: 1990	<i>Trailled agricultural rollers (= ISO 8912)</i>
BS 6550: 1985	<i>Recommendation for working widths of equipment for sowing, planting, distributing fertilizers and spraying (= ISO 6720)</i>		<i>Equipment for distributing granulated pesticides or herbicides (= ISO 8524)</i>
		BS AU 50	<i>Tyres, wheels and rims.</i>
BS 6621: 1985	<i>Determination of combine harvester capacity and unloading rate (= ISO 5687)</i>		<i>Agricultural tractors and machines</i>
			<i>Part 1: Section 4.1: 1989</i>
BS 6735: 1987	<i>Reach volumes for the location of controls on agricultural tractors and machinery</i>		<i>Designations and dimensions for existing (inch) series tyres (= ISO 4251/1)</i>
			<i>Section 4.2: 1989 Load ratings for existing (inch) series tyres (= ISO 4251/2)</i>
BS 6736: 1986	<i>Hand-signalling for use in agricultural operations</i>		<i>Section 4.3: 1989 Classification codes and nomenclature for existing (inch) series tyres (= ISO 4251/4)</i>
BS 6777	<i>Electrical connections for agricultural machinery</i>		<i>Part 2: Section 1b: 1980 Rim profiles and dimensions</i>
	<i>Part 1: 1986 Double pole connectors (= ISO 4165)</i>		

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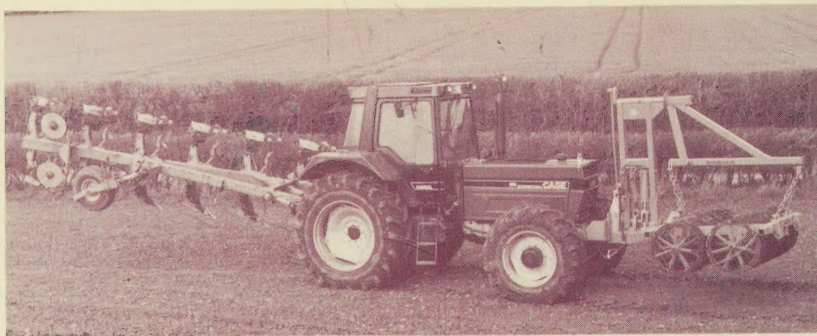
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