FARM MACHINERY

Ninth Edition

CLAUDE CULPIN,

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CLAUDE CULPIN,
OBE, MA, DipAgric(Cantab), FIAgrE

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By the same author

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Preface
To The Ninth Edition

This edition, like its predecessors, is written for farmers and those who advise them; for students of farm mechanization and agricultural engineering; and for those concerned with technical aspects of the supply of power and machinery for agriculture. The scope remains broadly the same as that of the eighth edition, but to save space and cost the chapter on Development and Economic Aspects of Mechanization has been omitted, since this subject is dealt with more fully in the companion volume *Profitable Farm Mechanization*. The revision is the most comprehensive ever undertaken.

As in earlier editions, the objective has been to deal with principles and this will ensure that most of the information provided will remain valid long after machines illustrated have been superseded.

With the impending use of metric units in agriculture, metric units or equivalents are used where appropriate, usually in addition to Imperial. Most of the figures used are purely illustrative, so equivalents where given are generally only approximations. In the case of heat units it is particularly clumsy and laborious to give both metric and Imperial units, so Chapter 23, which deals with environment control, has been converted fully to metric units. A table in Appendix 8 gives some useful conversion factors.

Where several firms make the same type of machine, illustration of a particular make does not indicate any expression of opinion concerning the relative merits of the products of different manufacturers.

Facts and opinions concerning farm machinery can change rapidly, and no one person can be familiar with developments in all branches of the subject. I shall be glad to receive advice concerning any inaccuracies.

Claude Culpin
Silsoe, Bedfordshire
1976

Acknowledgements

The author wishes to acknowledge valuable assistance kindly given by many individuals and firms in the 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.

D. I. Bartlett and B. R. Smith have helped me with revision of Chapter 23 (Environmental Control), and J. M. Beeny and Professor B. A. May with some aspects of metrication in the Appendices.

Figures 7.2, 9.2, 9.3, 9.4, 19.13, 19.15, 23.1, 23.2, 23.3, 23.5 and 23.13, reproduced by permission of the Controller of Her Majesty's Stationery Office, are from Mechanization Leaflets of the Ministry of Agriculture, Fisheries and Food.

The frontispiece shows the Hunter sugar-beet harvester (*Ransomes Sims & Jeffries Limited*).

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Chapter 1

Tractors: Use in Farming

The history of tractor development is too long to relate in this book. Landmarks along the road include the first use of an internal combustion engine in a tractor in the United States in 1890; the 'Ivel' tractor of 1901; the American Ford of 1917, and the International 'Farmall' of 1923. During the 1930s, the use of low-pressure pneumatic tyres soon became popular, and the first Ferguson system tractors incorporating three-point linkage with hydraulic draught control were introduced.

In more recent years diesel engines have rapidly become the accepted power unit for all British tractors apart from small motor hoes. The most important development, one which is continuing, is the upsurge of engine power. Wheeled tractors in the 100 horse-power class have been introduced by most of the British tractor manufacturers, and are increasingly used. Most tractors employ two large driving wheels at the rear and small steering wheels at the front; but with the increase in engine power, four-wheel-drive has become common. The most usual form has a rigid frame, a pivoting front axle and power-assisted Ackermann-type steering; but a general arrangement favoured for some of the largest tractors involves hydraulic power steering by means of a two-section articulated chassis. Large tractors tend to be used for a limited range of operations, the chief being tillage, combined tillage and sowing and forage harvesting. Safety regulations designed for the protection of tractor drivers and considered more fully later require most new tractors to be fitted with safety cabs; and other regulations are leading to the necessity for cabs which reduce the intensity of noise at the tractor driver's ear. Drivers' seats are also being improved to reduce spinal and intestinal injuries caused by excessive vibration, and controls designed to improve ergonomic aspects of tractor driving. Most modern tractors are truly 'all purpose'. They can operate a vast range of mounted, semi-mounted and trailed implements and machines, and have hydraulic devices to provide easy and accurate control of the equipment from the tractor driver's seat. It has now become normal practice to provide electric starting, lights and light-signalling; other developments that have rapidly become commonplace include such items as multi-speed gear-boxes, live power take-off, differential lock, power steering and various devices for transferring weight from mounted implements to the tractor's drive wheels. The live power take-off ('live drive') is an asset with many p.t.o.-driven machines such as mowers, forage harvesters and pick-up balers. It enables the driver to check the tractor's forward motion while the machine clears itself. A 'constant-running' drive to the hydraulic pump is a great advantage with many implements that are operated by the tractor's hydraulic system. For example, 'live hydraulics', as it is sometimes called, enables the tractor driver to continue to raise a loaded manure fork as he backs away from the heap and manoeuvres his tractor towards the spreader or trailer.

The differential lock now standard on nearly all tractors on sale in Britain is mainly used in ploughing, where the land wheel almost always tends to slip before the furrow wheel – partly because of the difference in ground surfaces, and partly because the furrow wheel inevitably carries more of the tractor's weight.

Power steering is fitted as standard on several of the higher horse-power tractors, and it is a necessity on all the large four-wheel-drive tractors. Some developments have not caught on quite so rapidly as was at first anticipated. These include ground speed power take-off and hydraulic transmission.

The hydraulic transmission systems that have been successfully applied to farm tractors are mainly of the hydrostatic type, as opposed to the hydro-kinetic type used on some expensive cars.

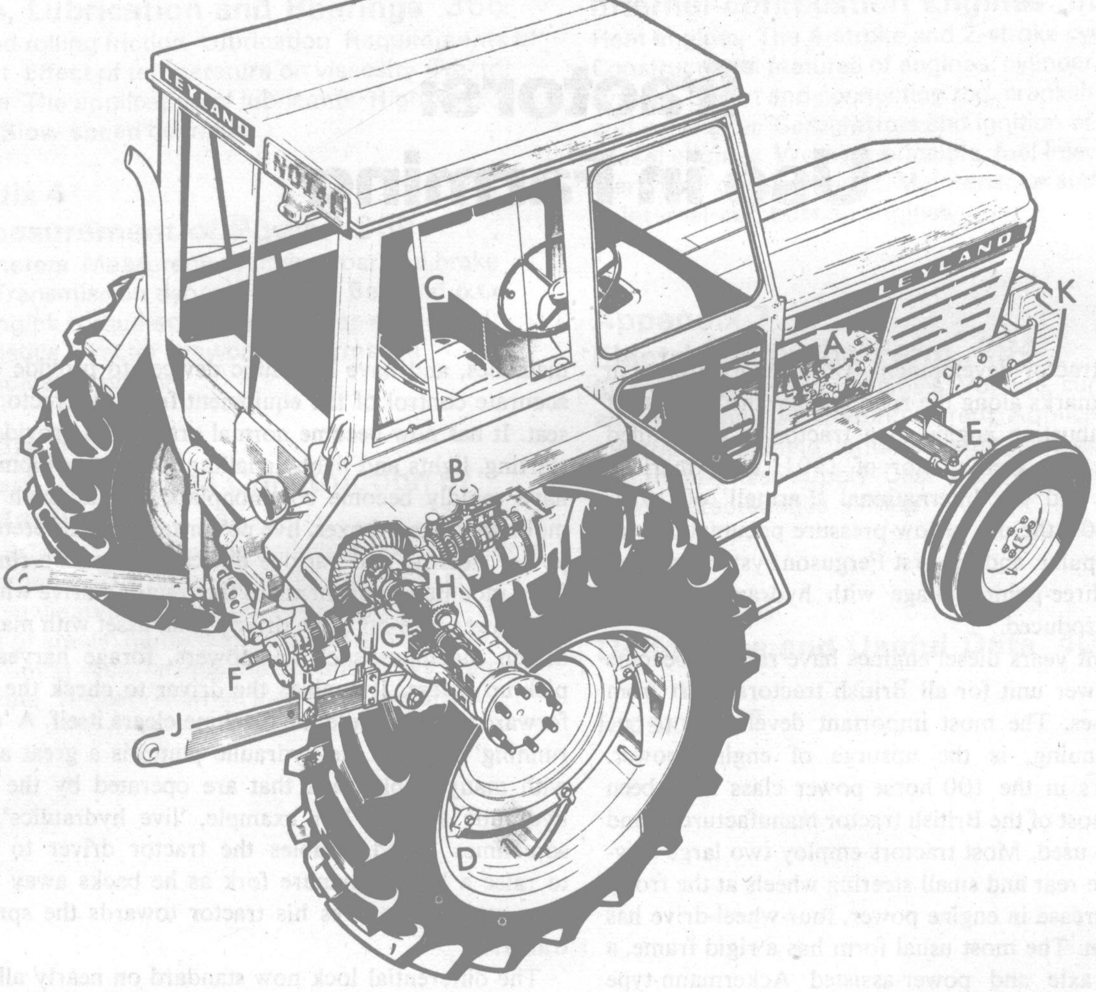

Fig. 1.1 Characteristics of high-power rear-wheel-drive tractor (*Leyland*)
A High-torque engine B 10-speed gear-box C Safety cab D Power-adjusted variable-track drive wheels E Power steering F Independent two-speed p.t.o. G Multiple wet plate disc brakes H Epicyclic final drive J Category Two linkage with assister rams for heavy implements K Front weights

The step-less speed change provided by a hydraulic transmission system is clearly advantageous for many purposes; but since some modern tractors provide up to 12 forward speeds by mechanical transmission, the advantages of the hydrostatic transmission are less than they would have been in the past. This is particularly so when a finger-tip controlled power-shift system is installed to make it easy to change gear on the move.

There are obvious advantages in a high p.t.o. speed where high powers have to be transmitted and the principal mechanisms run at a high speed, as in flail type forage harvesters. The 1000 rev/min p.t.o. speed is an ISO

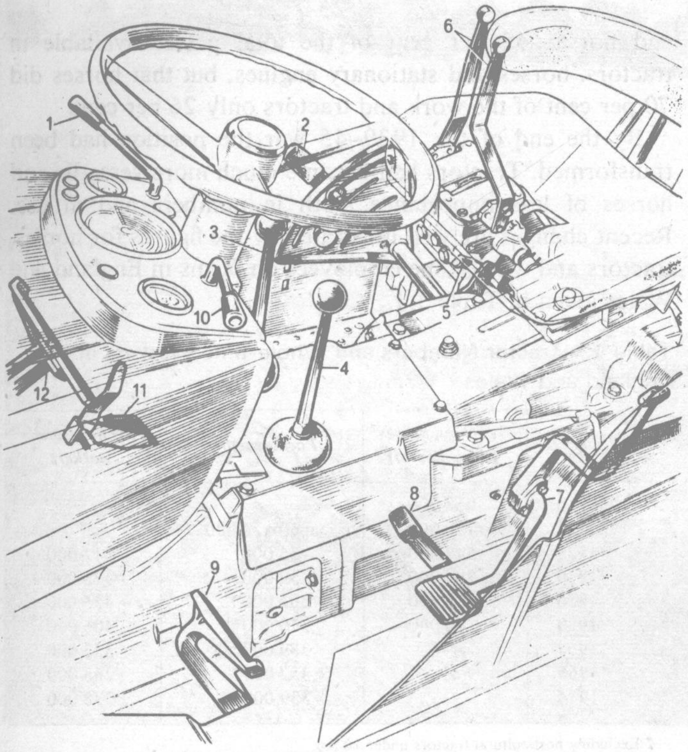

Fig. 1.2 Controls of all-purpose tractor (*John Deere*)
1 Hand throttle 2 Hydraulic lift/lower lever 3 Gear shift lever with four positions 4 Gear range lever (high, low or reverse) 5 Hydraulic selector lever (provides for load control, depth control, or combined load and depth control) 6 Hydraulic external cylinder controls 7 Hand/foot control for differential lock 8 P.t.o.-engagement lever 9 Clutch 10 Hi-Lo transmission lever (gives immediate ground-speed reduction of 26 per cent without declutching) 11 Foot throttle 12 Brake pedals (latched) (Reproduced from *Farm Mechanization and Buildings*)

Standard. It is available in addition to 540 r.p.m. either as standard or as an optional extra on most British tractors. The 1000 rev/min p.t.o. shaft speed allows shafts and universal joints to be kept small, but the vibration of a high-speed shaft with two Hooke's joints is acute under some conditions.

Use of a single constant velocity joint, so that no cyclical speed variation (which causes the vibration) occurs, unfortunately limits the angle of articulation between the tractor and the implement to 40°, which is insufficient for field work. Arrangements to increase this angle to 75° are likely to be costly and to make use of such mechanisms somewhat unattractive to implement manufacturers.

Few makes of tractor have ground speed p.t.o., and specifications are sometimes widely different from the British Standard of 1 revolution for every $7 \pm \frac{1}{2}$ in of forward travel. Technically, ground-speed p.t.o. drive would appear to offer advantages for drills and fertilizer distributors. Because so few tractors are equipped with ground-speed p.t.o., few implement manufacturers have so far attempted to make use of this fitting.

As tractor size progressively increases and implements become heavier, there is more and more to be said for a device like a pick-up hitch which allows the implement to be coupled up to the tractor without the driver having to leave his seat. Quick hitches of various types were developed in America and one of these, which was introduced by John Deere in 1960, was designed to be used between the standard three-point linkage and slightly modified implements. After a study of this hitch by other American manufacturers, an American Standard Quick Hitch, applicable in different sizes to all three categories of three-point free-link hitches, was agreed and published.

In the meantime, developments with the same objective had been pursued in other countries, notably Germany. Among the designs favoured were some with a matching triangular framework on both tractor linkage and implement headstock, as opposed to three hooks used in the ASAE Standard. It is claimed for the American Standard that it does not require any alteration of the standard tractor three-point linkage, and that the small design changes required on implement headstocks do not prevent easy conversion for conventional three-point hitch operation. These are important considerations. The American hitch is not quite as good as some designs incorporating matching 'A' frames in ability to pick up implements which are out of line with the tractor. There is also a small displacement of the implement rearwards in order to accommodate the hitch.

With an eye to the future, several research organizations both in Britain and abroad are actively engaged in the development of driverless tractors, using a variety of methods, none of which seems likely to be widely used in the near future. The only system in commercial use is one based on the use of a 'leader-cable' laid under the ground. A sensor carried on the front of the tractor is connected to the steering controls. This allows the tractor to follow a cable which has been laid out in an orchard in the pattern required for automatic mowing or spraying.

In the USSR experiments have been made with a tractor (a tracklayer) which guides itself on a straight line by following a leader cable anchored at opposite ends of a rectangular field. The cable is automatically transferred to the next path at the end of each traverse by the tractor's self-winding arrangement. The system appears suitable only for large rectangular fields.

Though 'all-purpose' tractors represent by far the most important group, there are also many useful specialized types which are only designed to deal with a limited range of jobs. For example, there are tracklayers for heavy cultivations in difficult conditions, and power-frame tractors which are particularly suitable for accurate row-crop work. Though the small self-propelled tool frame is very little used in Britain, this type is more widely used in some European countries where the power range includes models of 30 h.p. (22 kW) and 50 h.p. (37 kW) in addition to those of 20 h.p. (15 kW) or less.

A few machines are self-propelled, and incorporate a power unit and transmission system that does nothing but operate the one specialized machine. This has obvious drawbacks in the case of seasonal machines such as combine harvesters, and many efforts have been made to develop traction 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 Czechoslovakia, somewhat similar three-wheeled 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 corn harvest. In Russia, a four-wheeled chassis can be used as a general-purpose truck when not needed for harvesting.

A four-wheeled Dutch self-propelled power unit of 170 h.p. (127 kW) has a hydrostatic transmission giving infinitely variable speeds in any one of three gear ranges. Reversible controls facilitate driving with the smaller steering wheels either at front or rear. Two high-speed p.t.o.s are provided at both front and rear. The machine is designed primarily for the operation of mowers, conditioners and forage harvesters for either grass or maize.

Use of Tractors in British Farming

In the period between the first and second world wars the use of tractors in Britain increased steadily, but by 1939 the total number in use in England and Wales was still no more than 55 000, as compared with 549 000 working horses. A survey of tractor use in the Eastern Counties during the middle 1930s showed that tractors represented 42 per cent and horses 45 per cent of the total power available in tractors, horses and stationary engines, but that horses did 70 per cent of the work and tractors only 26 per cent.

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. Recent changes are well illustrated by the figures for horses, tractors and whole-time employees on farms in England and Wales given in Table 1.1.

Table 1.1 Tractor Numbers and Whole-time Workers in England and Wales

Period	*Working horses (agricultural)*	*Farm tractors*	*Whole-time workers*
1906–10	968 000	—	
1921–25	796 000	approx. 2 000	
1939	549 000	55 000	511 000
1950	289 000	259 000	575 000
1956	105 000	364 000*	455 000
1960	46 000	370 000*	406 000
1964	—	389 000*†	333 000
1968	—	352 000*	263 000
1974	—	339 000*‡	238 000

* Excluding horticultural tractors under 10 h.p.
† Note decline in tractor numbers after this date.
‡ December 1973.

The change from animal to mechanical power in farming is certain to continue. The steady increase in wages, and the need to obtain increased output from a restricted labour force, make it essential for farm workers to utilize mechanical power on an ever-increasing scale.

It is generally agreed that a man is capable of developing approximately $\frac{1}{8}$ h.p. (0·17 kW). The cost of this power, with wages at 80p an hour, is over £6 per h.p. hour (£8/kW hr). No farmer can afford to rely much on the unaided power of human muscles. The worker who is equipped with a tractor developing only 30 drawbar h.p. (22 kW) can provide power at the drawbar at less than 6p per drawbar h.p. hour (8p/kW hr). Agricultural progress depends largely on the extent to which mechanical power and machinery can be employed to render labour more productive.

Little research has been carried out on economic aspects of tractor utilization. Average annual use per tractor is about 700 hours.

Farms with low total tractor use requirements tend to have more tractors in proportion to the amount of work to be done. The number of tractors required for a particular farm depends not only on the annual amount of work to be

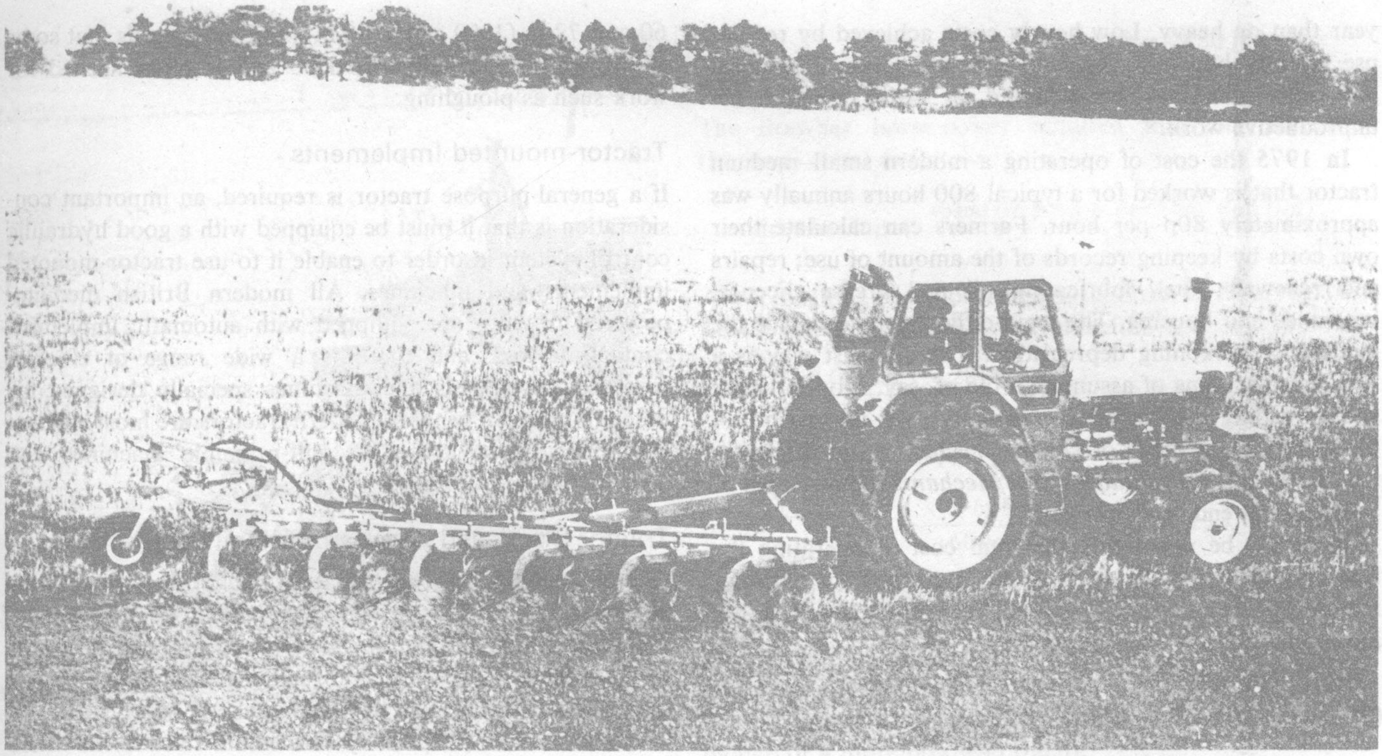

Fig. 1.3 The long semi-mounted plough operated by a high-powered tractor is depth-regulated at both front and rear by a torque-sensing ('Load Monitor') system (*Ford/Ransomes*)

done, but also on such factors as the time of year by which the work must be completed, and the speed at which particular types and sizes of tractors and equipment can work. Increases in the power of tractors and in working capacities of machines are drastically reducing the total hours of tractor use needed for particular farming systems.

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 South-Western 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 arable farms the peak month is usually at the time of spring sowing, in March–April. On grass farms it comes later, during the silage or hay harvest.

In considering the influence of the use of tractors on farming organization 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, the care the tractor receives, and several other items. One of the most important factors influencing cost per tractor hour is the amount of use. Low hourly costs are achieved on some farms by using tractors nearly every day of the year and doing all kinds of work with them. On light land it is generally possible to work tractors many more days in the year than on heavy. Low hourly costs achieved by regular use are not, however, necessarily an indication of efficient use, since this may be achieved by using tractors for unproductive work.

In 1975 the cost of operating a modern small–medium tractor that is worked for a typical 800 hours annually was approximately 80p per hour. 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, 8 or 10 years and spreading the capital cost equally over the period. A discussion of methods of costing mechanization processes may be found in *Profitable Farm Mechanization* (see list of references at end of chapter).

It should be noted that the total cost of operating the tractor considered above must be increased by approximately 80p per hour (1975 rate), since the driver's wages are not included in the calculation.

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 an 'all-purpose' machine which can be applied to almost any kind of farm work, including ploughing, cultivations, sowing, row-crop work, harvesting, transport and stationary p.t.o.-work. This will apply particularly to small farms where one or two tractors are required to do everything. On larger farms there may be sufficient of particular kinds of work to warrant using special types of tractors, e.g. large four-wheel-drive tractors to cope with the autumn cultivation in good time, or light tractors of the self-propelled tool-bar type for drilling and inter-cultivation of root crops. Market gardeners may require tractors specially adapted for work in vegetable crops, and such special needs are briefly considered in Chapter 2, 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 60 and 72 in (1·50 and 1·80 m) meet most needs, but some adjustment is normally provided and is often needed for work such as ploughing.

Tractor-mounted Implements

If a general-purpose tractor is required, an important consideration is that it must be equipped with a good hydraulic control system in order to enable it to use tractor-mounted implements and machines. All modern British medium-powered tractors are equipped with automatic implement control devices, and there is a wide range of efficient mounted implements and machines specially designed for use with them. In general, modern tractors are most efficient and economic when used as 'unit-principle' machines with their mounted equipment.

Tractor Sizes, and Standardization

One of the most difficult problems in choosing tractors for general farm work is to decide whether all the tractors should be of one make and size, or whether a range of makes or sizes should be selected to suit the various jobs. This needs consideration on any farm where more than one tractor is used, and especially on medium-sized farms where three or four tractors are used. The current (1976) range of ISO three-point linkage standards (R 730) includes Category 1, recommended for tractors up to 35 kW, Cat. 2 for 30–70 kW and Cat. 3 for over 70 kW. It is likely that Cat. 0 will apply to lawn and garden tractors up to 15 kW and Cat. 4 to 110–180 kW. Category 2 is most widely used, but Category 1 is used for many implements designed for use with small–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. There is, however, much to be said for sticking to one make and size of tractor on small farms, and in these circumstances choice will frequently depend as much on the range of mounted equipment that is available to go with the tractor as on the size or other features of the tractor itself.

On larger farms, there is considerable advantage in having more than one type and size of tractor, since this arrangement allows the matching of the tractor with the job in hand, and permits choosing the best equipment from more than one manufacturer. Operating more than one type of tractor necessitates keeping more spare parts on the farm, and requires the man responsible for maintenance to have a wider knowledge; but these are minor disadvantages com-

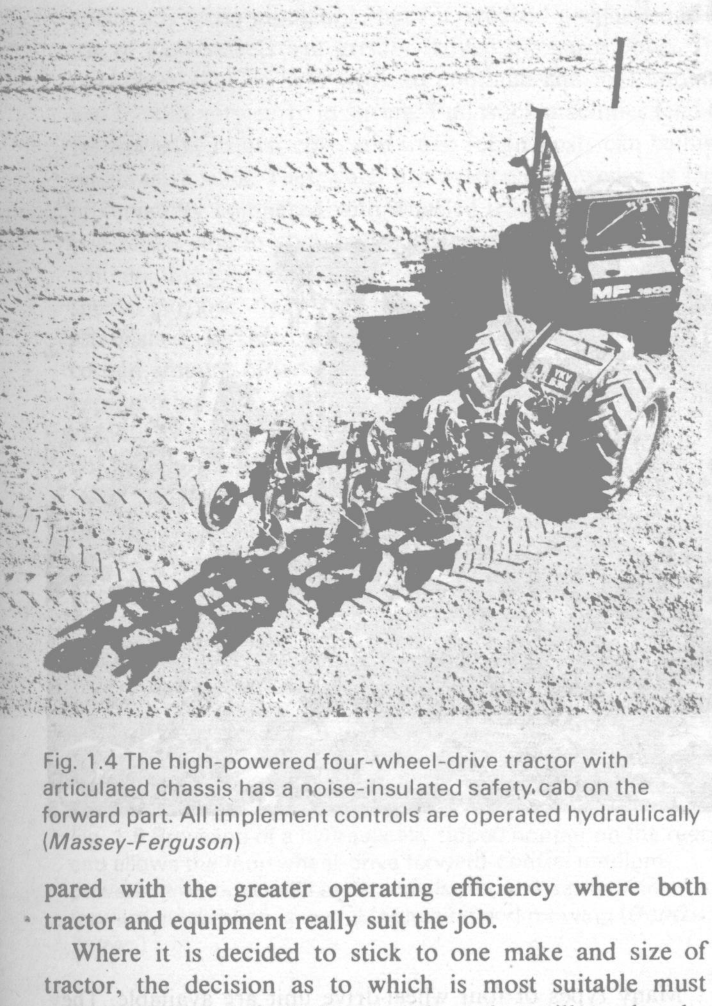

Fig. 1.4 The high-powered four-wheel-drive tractor with articulated chassis has a noise-insulated safety cab on the forward part. All implement controls are operated hydraulically (*Massey-Ferguson*)

pared with the greater operating efficiency where both tractor and equipment really suit the job.

Where it is decided to stick to one make and size of tractor, the decision as to which is most suitable must embrace a study of all the operations that will need to be carried out. Among the most important are ploughing and the basic cultivations, which must be done thoroughly and in good season, and will serve to illustrate the problems. 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/in^2 (34·5 kN/m^2) for very light blowing sand to over 15 lbf/in^2 (103·4 kN/m^2) for heavy clay, an average figure for medium loam being about 10 lbf/in^2 (68·95 kN/m^2) of furrow section. Thus, in average conditions, the drawbar pull needed to operate a three-furrow plough with furrows 12 in (305 mm) wide and 8 in (203 mm) deep would be

$$12 \times 8 \times 3 \times 10 = 2880 \text{ lbf}$$
$$(0{\cdot}305 \times 0{\cdot}203 \times 3 \times 68{\cdot}95 = 12{\cdot}8 \text{ kN})$$

The drawbar horse-power required may be calculated (Imperial units) as follows:

$$\text{drawbar h.p.} = \frac{\text{speed (m.p.h.)} \times \text{drawbar pull (lbf)}}{375}$$

At a ploughing speed of 4 m.p.h. the drawbar h.p. required for the above conditions would therefore be

$$\frac{4 \text{ (m.p.h.)} \times 2880 \text{ (lbf)}}{375} = 30 \text{ h.p. approx.}$$

In SI units, power = Nm/s (watts)

$$= 12{\cdot}8 \times 10^3 \times \frac{4 \times 1{\cdot}609 \times 10^3}{60 \times 60} \text{ watts} = 23 \text{ kW approx.}$$

Such a performance is just within the capabilities of a small–medium tractor of about 40 engine h.p. (30 kW), provided that conditions for traction are ideal. For heavier land, however, especially if the tractor is to operate on pneumatic tyres, it would be necessary to consider either a two-furrow plough or a more powerful tractor.

Cultivation performance is not the only factor determining the choice of tractor power, especially on the larger farm. Several specialized implements, especially those dealing with the harvesting of forage, require considerable power at the p.t.o. 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 p.t.o. 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.

Type of Engine

Before the 1939–45 war practically all tractors were powered by petrol or paraffin (vaporizing oil) engines. Because of the tax on petrol in Britain most tractor engines were, in fact, paraffin models. It was not until the early 1950s that diesel-engined tractors became popular, but by the later part of that decade diesel tractors were predominant. The reasons for this are not hard to find. The first cost of the diesel engine was at first higher, but this was more than balanced by the saving on fuel. (The higher efficiency of the diesel (see Appendix 6) results in appreciably lower fuel

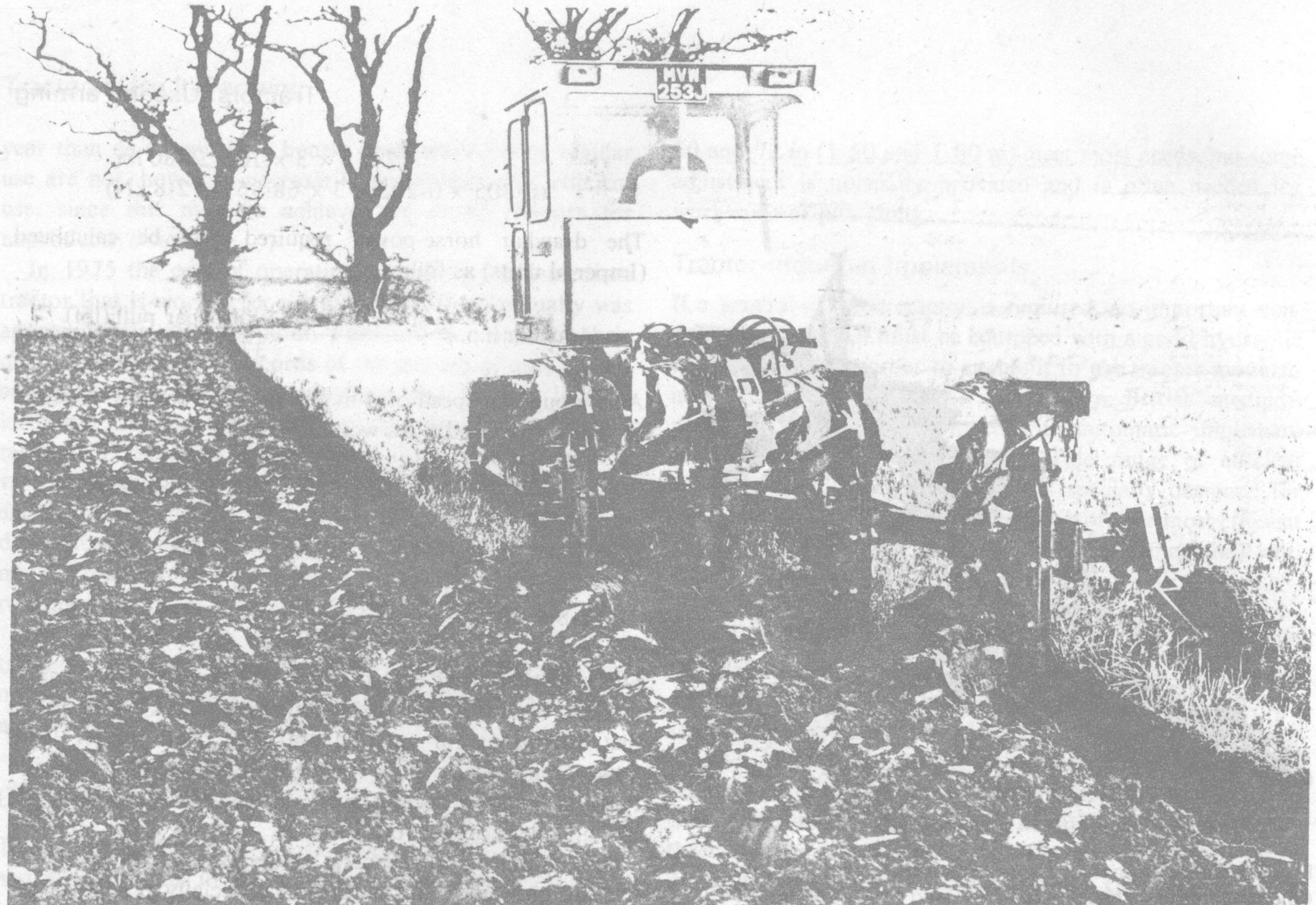

Fig. 1.5 The tracklayer, running out of the furrow and fitted with three-point-linkage implements, can work effectively in soil conditions that are too wet for some wheeled tractors (*Track–Marshall/Ransomes*)

consumption.) The modern diesel engine has every advantage as regards convenience of operation, being a reliable starter and immediately ready for hard work. Its good torque characteristics are widely appreciated. Though it may cost rather more to repair when an overhaul is needed, chiefly because of the fuel injection equipment, these repairs are generally less frequently required. The diesel is standard equipment in all modern British tractors other than small market garden machines; and with large scale production, capital cost has become very little higher than that of the vaporizing oil engines which have been displaced.

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.

Many types of four-wheel-drive unit are available. They have advantages over rear-wheel-drive for heavy cultivations or transport in difficult conditions, but do not necessarily give a better performance on medium-powered tractors where conditions for adhesion are good. The extra cost of four-wheel-drive is more easily justified on powerful tractors, where the unit replaces a tracklayer.

For heavy tillage operations the choice lies between the large wheeled tractor and the tracklayer. Both have their advantages. Wheeled tractors are able, when conditions are good, to work at higher forward speeds than crawlers; but when conditions are difficult their weight and excessive wheel slip may cause physical damage to certain soils. When ploughing in wet conditions the tracklayer may do less damage to soil structure because it runs out of the furrow. Large wheeled tractors sometimes create deep ruts with