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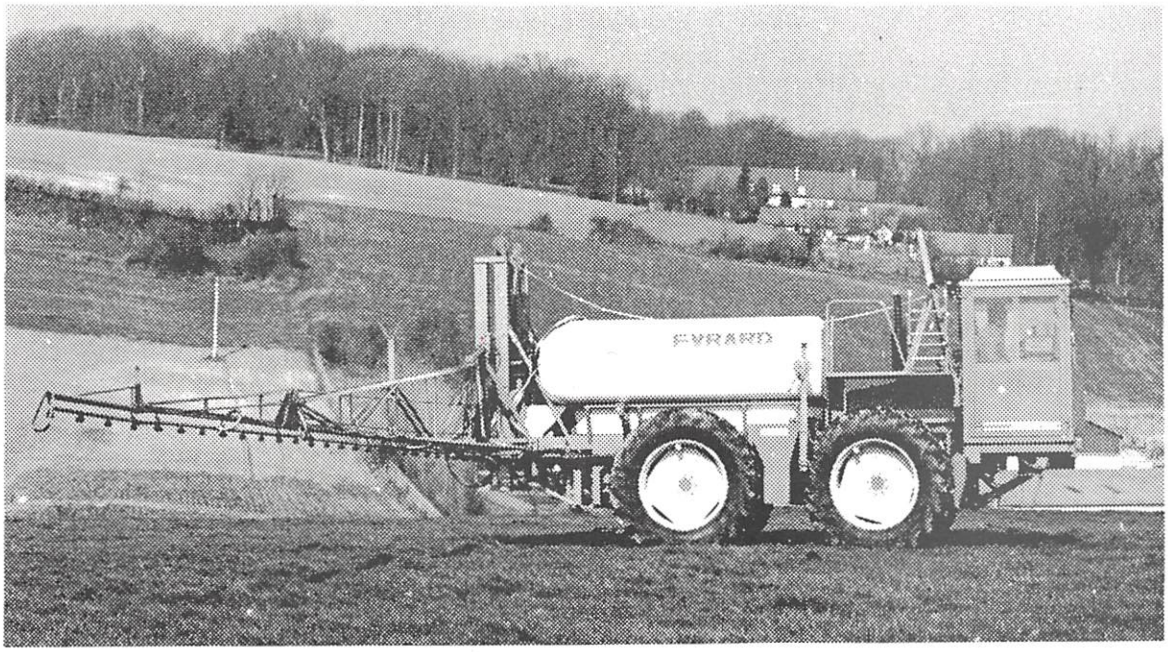
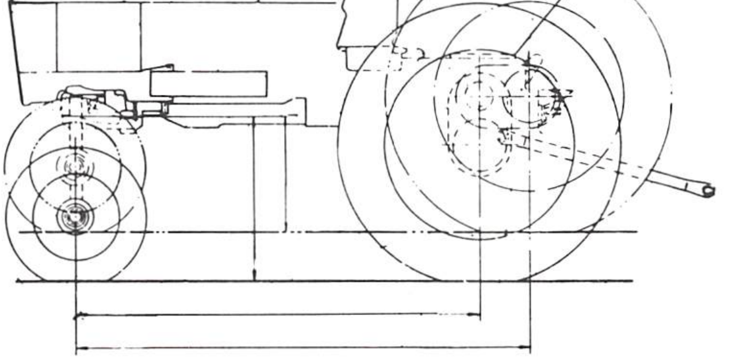


SPECIALISED PRIME MOVERS IN AGRICULTURE



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CONTENTS

Specialised prime movers in agriculture

G E E Tapp

THE Institution embraces within its membership a very wide spectrum of the agricultural and agricultural engineering industry including those engaged in research, design and manufacture, teaching, distribution and, not least, farming. The theme of this Conference, ***Specialised prime movers in agriculture***, was chosen by the Southern Branch as one which would have a wide appeal to the whole membership.

The Conference was attended by some 140 delegates including representatives from NIAE, NCAE, HSE, MAFF, NFU, BAGMA and all the UK tractor manufacturers.

What is a 'specialised prime mover in agriculture'?

Agriculture is defined as 'cultivation of the soil'. Prime movers first became specialised when man discovered that either by the selection of the correct animal or by selective breeding of a draught animal used for tilling the soil, he could obtain improved performance. Today the heavy draught horse, sadly reduced to a mere showpiece in most parts of the world, must rate as one of the most magnificent results of selective breeding to improve the physique and physical performance of an animal.

In little over half a century the majority of agriculture has come to rely upon mechanical prime movers, a prime mover being basically a vehicle designed to pull, push or carry (and possibly power) an implement or piece of equipment – in short, a tractor.

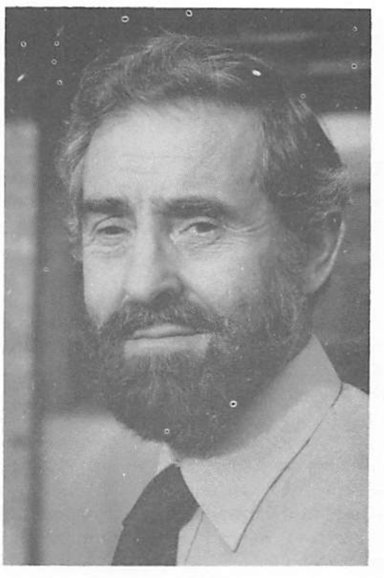
The standard (or in North American terms, regular) tractor has evolved into a four wheel machine driven by the rear wheels, powered by a diesel engine of between roughly 20 and 100 kW, fitted with a 3-point linkage and mechanical power take-off at the rear. This machine constitutes by far the greatest volume of tractors produced and performs the majority of work required in agriculture throughout the world.

Few would argue that the standard type of tractor described will continue to satisfy the main requirement for prime movers in agriculture for many years to come but as agriculture continues to develop so the requirement and demand for specialised prime movers increases. Not only is specialisation required to carry out operations better and more efficiently than can be done with a standard tractor, but in many cases to carry out new operations which either can only be achieved by manual labour at present or have not been carried out at all before. Even in developing countries where there may be an excess of hand labour available, the improved productivity resulting from the use of specialised prime movers will often justify their use.

It is evident from the first two papers, Vineyard and Orchard Tractors, by John Bennett, and High Clearance Tractors, by Lamar Williams, that there can be no firm dividing line between these two subjects, there being an important vineyard requirement for high clearance tractors. Discussion on these papers, however, showed clearly that whereas the vineyard tractor in its varying forms can accept a number of compromises in terms of ground clearance and durability and, by normal agricultural terms, can be a comparatively fragile tool, the straightforward high clearance tractor used in general agriculture must be of such structural strength to accept the roughest possible usage. It must incorporate a transmission matched to the full power of the engine when used for high tractive efforts.

In his paper on 'Large Four Wheel Drive Tractors', David Tapp shows how the requirement for four driven wheels has led to a number of different arrangements of transmission and steering and that North American requirements are by and large very different from those of UK and central Europe. He examines at length the reasons for and advantages in use of these machines. Particular attention is given to drive line and tractive efficiency, soil compaction and the factors involved in obtaining optimum tyre performance. This will no doubt form a useful reference document for future students of four wheel drive.

The paper on 'Forestry Tractors', by Airlie Bruce-Jones, provides a very useful and informative introduction to the forestry scene. The varied work requirements are shown to have been met by many very different prime movers, the variety and complication of some being difficult to justify. Above all it becomes apparent that the factors most valued by the forester are reliability, durability and simplicity. At the same time the economics of forestry apply severe constraints on the capital cost of all forest machinery.



Hugh Flatters persuasively puts the case for tracks in his paper on 'Crawler Tractors'. He reminds us of the crawlers early origins in England and carries on to explain that developments in material and sealing technology in more recent years have done much to reduce wear of tracks and running gear. This, together with the satisfactory adaptation of three point linkage will, he claims, ensure a continuing future for crawlers in agriculure.

Conference chairman Nigel Scott – an experienced agricultural contractor – was kept fully occupied controlling and guiding the discussion periods. Almost inevitably the papers on large four wheel drives and crawler tractors produced an element of crawler versus four-wheel drive controversy – discussion would no doubt have continued for much longer had time allowed.

Whilst it was never intended that the papers in this Conference should lead from one to the other in any logical sequence, since each speaker dealt with his own particular and separate subject, there is one common thread running through the papers: as agriculture develops throughout the world and as the demand for food and agricultural products (and this includes forestry) increases, so will the demand for specialised prime movers increase.

Neither in the papers nor in subsequent discussion was the question of regulations governing safety or those for road use mentioned. It is pertinent to mention here that the majority of international and national standards and regulations concerning tractors have been written around the 'standard' tractor.

It is one thing to design and develop a tractor to be produced in tens of thousands, where compliance with regulations is merely a hindrance, but it is another matter entirely to develop a machine to be produced in the odd thousand, hundreds or even tens, where the multiplicity of regulations may render the whole project either impossible or uneconomical.

With specialised machines it is important that the designer is free to experiment and develop the machine as far as possible unhindered by regulations. It is becoming increasingly important, therefore, that those involved exercise the greatest possible vigilance on any proposed regulations or laws which may affect their future. It is, of course, in this sphere of engineering development that there is great opportunity for the agricultural engineer employed within the small to medium sized company. It is here that an up-to-date knowledge of agricultural requirements combined with a sound engineering background can be the most valuable assets a designer can have, and this must surely be an area which offers great opportunities to trained and qualified agricultural engineers.

Vineyard and orchard tractors

John Bennett

Summary

THE name 'vineyard or orchard tractor' is a general term covering a wide range of machines. The bulk of the requirement is supplied by the major tractor manufacturers with special versions of standard tractors but the requirement for tractors specifically designed for particular circumstances is met by a very large number of small manufacturers each satisfying a particular or local need.

Introduction

THE popular concept of a vineyard tractor is a special narrow version of a small standard tractor. In many cases this is almost the truth.

The easily distinguishable variations of the vineyard tractor theme are:—

1. The narrowest possible version of a standard tractor; this is the most popular type, used in large quantities throughout the wine growing areas of France, they are also widely used in other markets.
2. The slightly wider version of 1. This type is also used extensively in France, particularly when other operations besides wine growing are undertaken.
3. Four-wheel drive versions of 1 and 2. These are particularly associated with Germany and Italy, where the vines are often grown on steep hills, and the maximum traction and stability are necessary.
4. Four-wheel drive, pivot steer tractors, with equal sized wheels. This type is popular in Italy. It is the best type from the point of view of traction, stability, and overall height.
5. Straddle-type tractors. These are very high clearance machines designed for working in vineyards with very close row-spacing. They are used in parts of France, but as vineyards are re-planted the tendency is to plant wide enough for the conventional vineyard tractors since the straddle type has obvious disadvantages of cost, complexity and problems of stability and versatility.
6. Walk-behind tractors. Ordinary garden cultivators are often used in smaller vineyards. They can be adapted to perform practically all the operations required.
7. Winch. For the steepest of slopes, the winch and cable system is the only alternative to hand operations.

An orchard tractor is easier to define than a vineyard machine. It is basically a standard agricultural tractor with modifications to reduce the overall width and height, and to avoid damage to trees from unnecessary projections. In fact, an orchard tractor is really one particular type out of the range of vineyard types.

The market

Within Europe the total number of vineyard and orchard tractors sold is approximately 15 000 per year, compared with a total number of all tractors of about 350 000. Just over four per cent is a small proportion, but the percentage varies from virtually nil in Scandinavia to about 12 in France where about 8000 tractors are sold annually. It is, therefore, the French market that influences the design and specification of vineyard and orchard tractors, although Germany, Italy, and Spain have their own special requirements.

Vineyard tractors

The conditions in which a vineyard tractor must work are as varied as any, and the designs which have evolved to meet the requirements range from the ordinary to the fantastic; it all depends on how the vines are grown. In France about five per cent of the vine growing area has the vines planted in rows 2.2 m apart and more. These are

John Bennett MA, product planning specialist Massey Ferguson Company.

Paper presented at the Autumn National Conference of The Institution of Agricultural Engineers, held at The Lorch Foundation, Lane End, nr High Wycombe, Bucks, on Tuesday 10 October 1978, when the subject was Specialised Prime Movers in Agriculture.

A typical vineyard tractor.

mostly in the south east region and in these vineyards a tractor only a little narrower than normal can be used.

About 85% of the vineyards space the vines between 1.5 m and 2.2 m, and for these the tractor has to be designed as narrow as possible; it is still basically a conventional tractor, but with special rear and front axles, special steering gear and modifications to controls, and seating, etc. The minimum width achievable is determined by the width of the tyres and the need to place the driver's seat partly between them. An otherwise conventional 30–37 kW (40–50 hp) tractor can be reduced to an overall width of approximately 0.95 metres when fitted with 9.5/9-28 tyres.

Some ten per cent of the vines are grown at row spacings less than 1.5 m, and it is not practicable to operate a normal tractor in these vineyards. For these conditions the 'straddle' type of tractor has been developed, with extremely high clearance and little more than the width of the tyres between the vines. These machines are built by specialist manufacturers to varying degrees of sophistication; some of them are conversions of standard tractors, and some of them are purpose designed machines.

The detail specification requirements of vineyard tractors are related to the range of operations that have to be performed and to the working conditions. Considering firstly the vineyard tractor that is a narrow version of a standard tractor:—

1. It must be narrow, but not unnecessarily narrow. Excessive 'narrowness' inevitably means compromises on the ergonomics of the tractor and difficult access to the driving seat. Thus it is necessary to offer a tractor in various widths to suit local conditions.
2. It must have a low centre of gravity. Obviously these tractors are not very stable laterally, and the stability must be optimised for safe operation.
3. It must be 'streamlined' to avoid damaging vine shoots as they brush past, and it must not have snagging points to catch on leaves and branches.
4. It must have an effective draught control system and a well balanced 3-point linkage. A lot of vineyard work involves cultivations at very shallow depth, and the implements are considerably extended to the rear, so that a sensitive draft control is essential. Also the implement must be well controlled laterally since the cultivation is carried out very close to the vines.
5. Rotary cultivators are extensively used, so that sufficient pto power must be available. It is also important that the available pto power at 540 r/min should be as great as practicable since some pto driven machines, particularly blower/sprayers, need a lot of power and must be driven at the standard speed.
6. A wide range of speeds is important with close ratio spacing. Slow forward speeds at maximum engine speed are important for rotary cultivators.
7. Many operations make use of external hydraulic power,

notably pruning machines, so that sufficient external oil flow and the means to control it must be provided.

8. The lift capacity should be sufficient to handle the large capacity sprayers commonly used, and it follows that sufficient front and weight must be provided. The type of add-on front weight that protrudes in front of the tractor is not suitable since it increases the effective turning circle.
9. The turning circle 'between walls' should be at the absolute minimum, especially on the narrowest models; this is because the vines are often grown on terracing and the turning space is kept to a minimum. The turn from one row into the adjacent row is always a very tight one, and effective independent brakes are important.
10. To counter some of the demanding requirements listed here, there are some specification areas where the requirement for a vineyard tractor are less demanding than those for a standard tractor. Ground clearance is not critical, and the maximum road speed is not as important as it is on standard tractors.
11. The wider versions of vineyard tractors need to maintain a high standard of control ergonomics and access to the driving seat.
12. The wider versions should also be able to achieve relatively wide track settings, so that they are able to perform normal tractor operations such as ploughing. This is because wine growing is sometimes combined with market gardening, and the same tractor is expected to perform in both operations.

It is much more difficult to be precise about the specification requirements of the straddle type of tractors. The requirements vary greatly with the locality, and the specialist manufacturers are able to adapt their basic products for individual applications. Mostly these machines are used for spraying, and pruning and other non-tractive operations, although many of them can be adapted for cultivations.

The simplest type is a conversion of a standard tractor, usually with a chain drive to the rear wheels and a special front axle. This type is suitable for spraying. Elaborations on this theme include the means to adjust the track width, and the means to adjust the clearance. The most elaborate machines can adjust the track width and self-level themselves whilst moving.

Other straddle-type tractors are purpose built, using proprietary engines and transmissions. This enables them to be made lighter and thus more stable.

Clearly these extra high clearance tractors are very expensive, and they are only purchased when it is quite impossible to use a narrow tractor. Generally, this is for spraying operations when the vines have grown out and the free space between the rows is very limited.

The walk behind tractors are really beyond the scope of this subject, but suffice it to say that in Italy particularly, these two-wheel tractors have been developed to a remarkable degree of sophistication. They are available up to and over 15 kW (20 hp) and very versatile, with accessories for ploughing, cultivating, spraying, irrigating, trailer work, snow-blowing, etc.

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High clearance tractors

Lamar Williams

Summary

APPLICATION of high clearance tractors in agriculture is limited, by economic and functional restraints, to specialised crops characterised by high labour requirement.

The general design details, functional features and market uses are discussed in this paper.

Market requirements

TODAY, high clearance vehicles are used on a considerable variety of crops, including vegetables, grapes, nursery, tobacco, cotton, cane and even cereals. Operations include basic tillage, seed bed preparation, planting, fertilising, insect and weed control and harvesting.

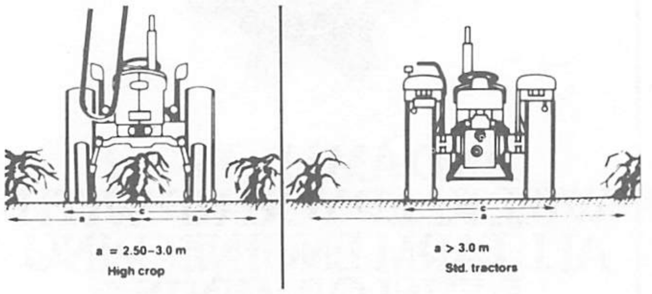


Fig 1

The distinguishing characteristic from the normal practice is uniquely that of the machine straddling the crop row or rows (fig 1). General types of cultural practices where high clearance vehicles are used are shown in table 1.

Table 1

	Ploughing	*Planting*	*Seed bed preparation*	*Cultivating*	*Spraying*	*Harvesting*
Cereals					X	
Grapes				X	X	X
Tobacco				X	X	X
Vegetable		X	X	X		X
Cotton					X	X

The relative production of these crops in select world areas is as shown in table 2.

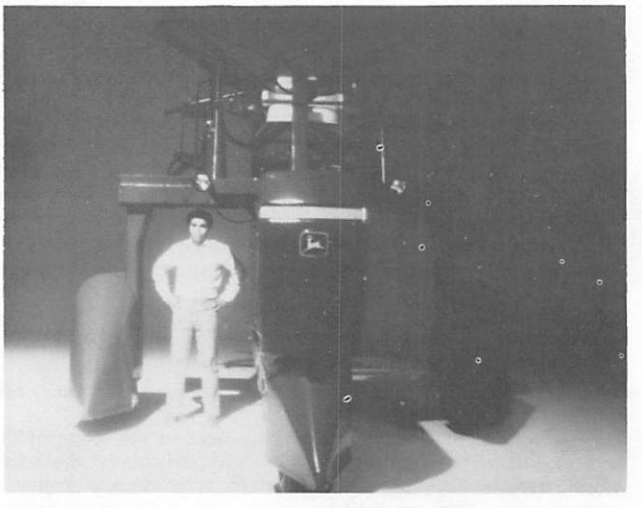
Table 2

	Production (1000 metric tonnes) 1976				
	Cereal	*Grapes*	*Tobacco*	*Vegetable*	*Cotton*
World	1 477 348	59 204	5687	311 777	12 695
W Europe	141 311	30 992	418	47 450	162
UK	13 466	–	–	3 605	–
N America	301 802	3734	1056	24 786	2298
Oceania	18 837	772	21	1625	24
Latin America	87 081	5781	695	13 843	1292
Spain	12 155	4078	29	7500	48

Source FAO production yearbook

Two pertinent observations can be made from these two charts. First that the high clearance vehicle does not perform all the operations for any single crop, and secondly that the crops in which the high clearance vehicles are used most intensively are those of lower total production in the world.

Fig 2 (above) Fig 3 (below).



Also, these crops are those which still require extensive labour input to the total energy requirement of raising the crops.

Special purpose high clearance vehicles such as the crop harvesters, (fig 2 and 3) and crop sprayers, have been developed to mechanise a manual function which limited production. This mechanisation permitted ever increasing size of farms which, in turn, supported more sophisticated machines. In the world today, we can compare this cycle fixed in each development stage by observing the under-developed, developing and developed countries. With any machine, and in particular with these limited purpose machines, the market only supports the economic justification where operation size is large. Otherwise a machine is discarded because of superseded design before it is worn out. On the other hand, the general purpose vehicle which is adapted to high clearance use is still a multiple use vehicle even though the use is sometimes limited to specific crops. The trend now, supported by economics of the farmer as well as of the manufacturer, is to continue the increasing flexibility of these units to cover more completely the special crop operations as well as other supporting operations of the related enterprise.

In general, there are two types of high clearance vehicles: the tractor or prime mover that is a modification of a conventional design agricultural tractor (fig 4) and the specialised limited purpose vehicle (fig 5) produced by assembly of components from a variety of mass produced vehicles and usually with some special function components added.

The very modern single purpose vehicles such as the cotton picker and tobacco harvester, have developed from one or the other of these two general types until now they are, in themselves, standard vehicles.

Both types of high clearance vehicles are being developed into

Lamar Williams, BS Agr Eng Mem ASAE Mem SAE manager, product eng John Deere, Iberica, Spain

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Fig 4 (above). Fig 5 (below)

more flexible and versatile machines, reaching ever closer to a complete crop husbandry mechanised system. The high clearance unit (fig 6) is one of those now on the market which are intended to provide several, if not all, the machine functions required for a given crop.

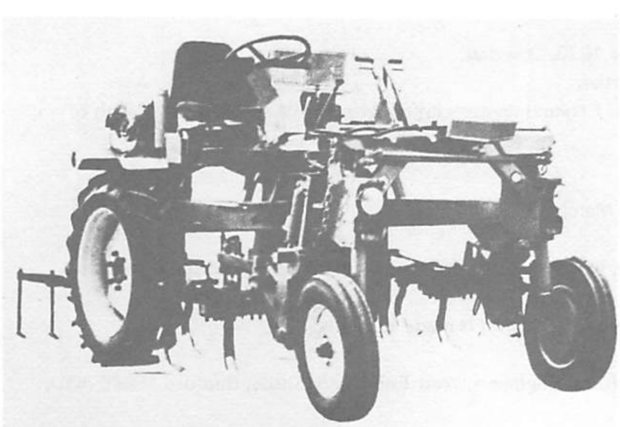
This vehicle utilises standard components for all power generation and transmission, the power from the engine being transmitted by roller chain to the driving wheels.

In other units, hydraulic wheel motors, which provide very good ground speed control and manoeuvrability, are employed.

The alteration of a conventional tractor to a high crop model provides an economy of manufacture and versatility of function to fill specific market requirements. To illustrate this, a particular vineyard market is used.

Seven tenths of the world vine culture (10 million ha) grow in Europe, including one million ha in the USSR. Five countries, however, have the major portion of this production, as shown:—

Fig 6



Country	*Vineyard (1000 ha)*	*Wine production ($l \times 10^6$)*
France	1772	8735
Spain	1600	3637
Italy	1400	7100
Portugal	355	1380
W Germany	100	626

The vineyard culture and mechanisation practices vary considerably in these countries and more specifically within vine culture regions. Practices vary from steep hillsides where only cable tow can provide mechanised power, to the high trellis vineyard of France and the low bush Spanish vine.

The centre spacing between rows also varies between areas, with type of grape, and with age of the vineyard.

Some of the necessary parameters for a prime mover tractor are influenced by the total farm enterprise, as well as by the specific crop. A relatively large sector of the vineyard operators include livestock and cereal production in the total enterprise. Unless the vineyard is of considerable magnitude relative to the total farm, some compromise must be accepted in matching equipment for universal usage or compatability with cereal and livestock operation within economical boundaries. This situation prompted the concept of a 'multi-crop' tractor (fig 7).

A conventional chassis configuration for heavy draught, integral implements and pto driven implements utilised in cereal and livestock operation, and a convertible unit (fig 8) with an increased ground clearance unit is obtained by a relatively simple and quick mechanical adjustment of front and rear axles.

Outboard final reduction in rear axle shaft drive (fig 9) and telescoping front axle spindles (fig 10) make this a relatively simple but effective design. The concentric housing and single mesh gears of the rear unit permit rotation of the housing for changing the

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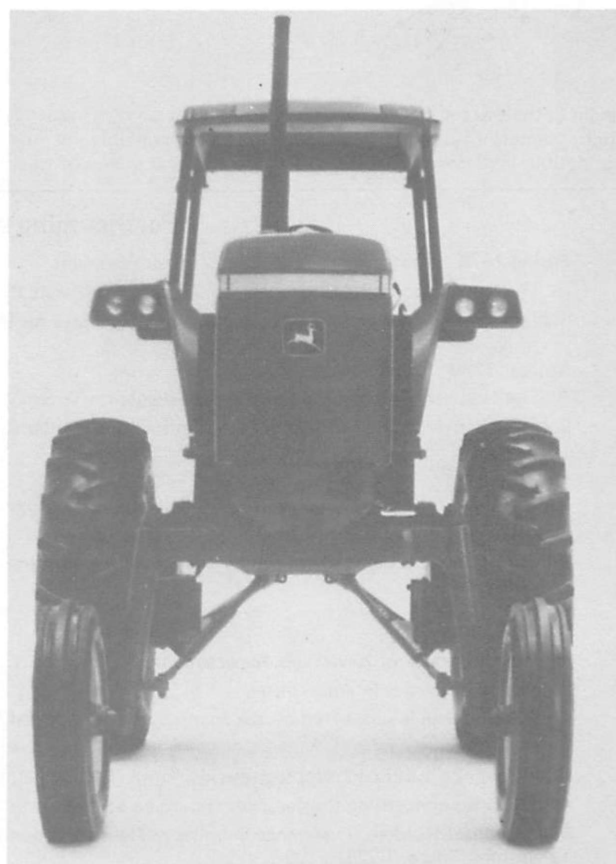
Fig 7



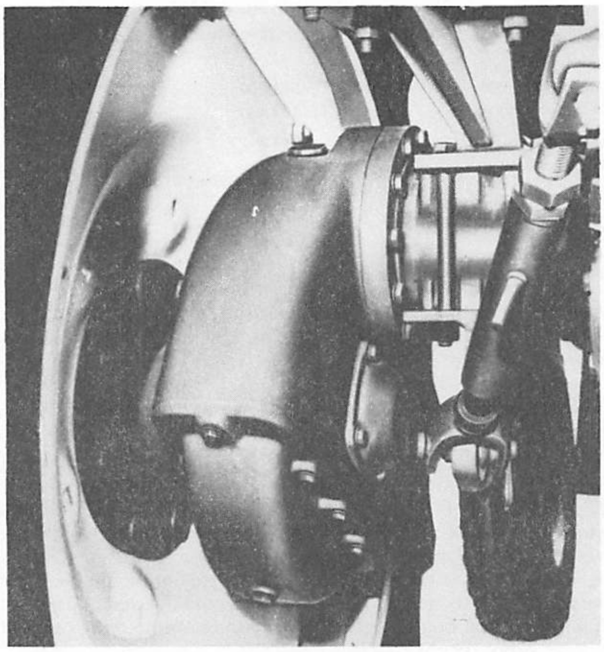
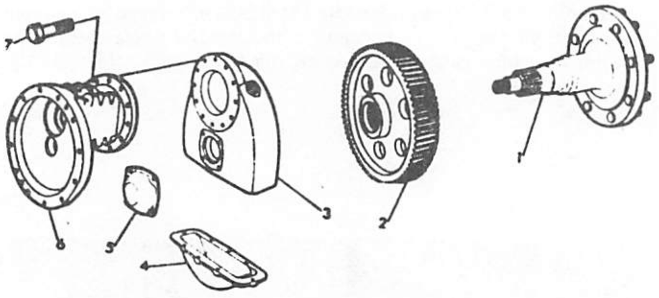


Fig 8 (above). Fig 9 (below)



height of the tractor. All the auxilliary equipment such as implement hitch, remote hydraulics and pto are still available to make compatible implement operation. There are several makes of tractor

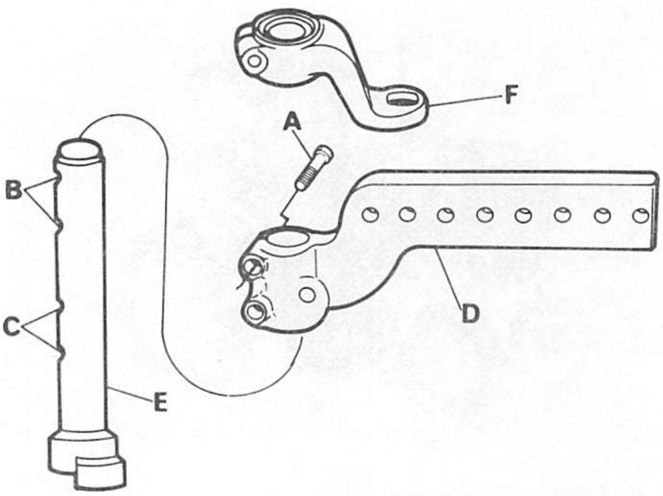


Fig 10.

being modified by local dealers. I believe David Brown and John Deere are the only manufacturers to date making this a factory option.

Future trends

The FAO agricultural statistics show a slight trend of increasing tillable area in the world, primarily for basic cereal crops. Also, a slight yearly increase of total production of these identifiable 'special tractors' crops is evident, due in large part to better management practices. However, I do not believe either of these increases will be controlling factors influencing the use of application of high clearance vehicles. The continued increase of mechanisation level (more capital and energy intensivity), size of farm and the mix of culture within the total farm or enterprise are the determining influences.

In a free enterprise system, mechanisation will continue to increase and units will continue to grow; thus I believe use of high clearance units will continue to grow. Both the engineer and the agronomist, along with the end user, will have a hand in shaping the future machines. The agronomist will work to develop the plant itself into a structure more compatible with machine capabilities and still providing qualities desired. The engineer will continue to provide cost effective designs to meet the market requirements. The end user will accept and utilise this improved technology as his economic enterprise justifies.

Forthcoming National Conferences

Spring 1979 (In association with East Midlands Branch)
At The Key Theatre, Peterborough, on Tuesday 20 March 1979. One day.
Subject: Mechanisation in the Production of Vegetables for Processing.

Annual 1979
At The National Agricultural Centre, Stoneleigh, on Tuesday 8 May 1979. One day.
Subject: Efficient Use of Resources – Implications for the Agricultural Engineer.

Autumn 1979
At The National Agricultural Centre, Stoneleigh, on Tuesday 9 October 1979. One day.
Subject: Tillage Equipment Design and Power Requirement in the Eighties.
This Conference is being organised by the Royal Agricultural Society of England, in association with the West Midlands Branch of the Institution.

Spring 1980
At The University of Newcastle, Newcastle-upon-Tyne, on Tuesday 18 March 1980. One day.
Subject: Electronics in Agriculture.
This Conference is supported by the Institution of Electrical Engineers, in association with the Northern Branch of the Institution.

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All enquiries concerning Conferences should be addressed to:
Mrs Edwina J Holden, Conference Secretary, The Institution of Agricultural Engineers, West End Road, Silsoe, Bedford MK45 4DU. Telephone: Silsoe (0525) 61096.

Large four wheel drive tractors

David R F Tapp

Summary

THE characteristics of the modern four-wheeled drive tractor are reviewed in the light of two-wheeled drive performance. Particular attention is paid to tyre performance.

Large four wheel drive

THE large four wheel drive tractor is a very broad subject and for the purpose of this paper 'large' has been defined as four wheel drive machines above 70 kW which, by North American standards, may still be a small tractor but by European and many other world standards is entering into the area of large tractors.

The second term to define is four-wheel drive, a term which is very loosely used by engineers to cover a wide range of vehicles. In the *Red Book*[1] — which is the reference book for tractors and machinery sold in North America — 'agricultural wheel type tractors four wheel drive' are those tractors with four equal sized wheels. Tractors with small driven front wheels are termed as 'agricultural wheel type tractors two wheel drive with front wheel drive option'.

During the course of the paper, where four-wheel drive is referred to, the term will refer to those machines with four equal sized wheels. Tractors with small driven front wheels will be referred to as unequal four-wheel drive or tractors with small front-wheel drive.

The four-wheel drive should be considered as a vehicle type completely in its own right, having been originally developed to offer a machine with all the flexibility and versatility of the standard two wheel drive agricultural tractor yet in addition the ability to give high drawbar pulls at slow speed and to operate under adverse ground conditions. There is a tendency for four-wheel drive to be considered only as a high traction vehicle, but during the course of the paper it is proposed to examine some of the advantages which four-wheel drive offer over two-wheel drive and also to examine some of the methods chosen by manufacturers to obtain the drive on all four wheels.

The unequal size four wheel drives are basically an extension of the two wheel drive, offering some improvement in traction and steerability under adverse conditions but not offering all the advantages of the equal wheeled four-wheel drive.

The first equal wheeled four-wheel drive to be produced in any commercial quantity for agriculture was the County Fourdrive which started production in 1955, a vehicle which was clutch and brake steered, like a crawler tractor, but instead of tracks used four equal sized driven wheels. For the purpose for which it was originally designed, ie use in the Caribbean sugar cane areas, the machine was very successful, but a little expensive. It was not suitable for UK and European type farming operations.

It was in 1960 that County produced the first equal wheeled four wheel drive with conventional front steering. A twin drive shaft system similar to the one currently used was chosen, with the drive to the front axles being taken via the bull pinion gears on the tractor unit rather than from the sun gear shafts as in today's design. This design was highly successful and was able to compete very favourably with the crawler tractor which was based on an identical power unit[2]. It is interesting that the UK at about this time of agricultural tractor development, did produce a considerable number of equal wheeled four-wheel drives. One can recall the first pivot steer agricultural tractor, the Matbro and the Bray Centaur which in some respects was a long way ahead of its time with front and rear mounted linkage and reversible controls. There was the forerunner of the Muir Hill range, the Northrop, the twin coupled tractors of the Doe Triple D, and later Roadless also produced an equal wheeled machine although they had been in the field of the small front-wheel drive from the mid-1950's.

David R F Tapp CEng MIMechE MIAgrE, Director, County Commercial Cars Ltd.

Paper presented at the Autumn National Conference of The Institution of Agricultural Engineers, held at The Lorch Foundation, Lane End, nr High Wycombe, Bucks, on Tuesday 10 October 1978, when the subject was Specialised Prime Movers in Agriculture.

Even today the indigenous four-wheel drives lead the field in the UK. We have the:—

COUNTY range of tractors using the unique drive system — the single lockable differential in the rear of the tractor and drive shafts driven from the rear axle passing down either side of the machine to drive the front wheels, both wheels on each side being coupled together. The tractors are equipped with steering

brakes which act on both wheels on the same side and give full braking on all four wheels for road work. The drive to the front wheels is not disconnectable. County currently offer a range of four-wheel drive tractors from approximately 55 kW up to 115 kW.

MUIR HILL — the drive system uses a drop box with the rear axle bolted directly to it and a drive shaft passing forward under the gearbox and engine to the front axle. Both axles are equipped with differential locks and the steering brakes act on both wheels on the same side. The tractor is equipped with full braking on all

four wheels and the drive to the front axle is disconnectable. The range of four-wheel drive tractors offered is from approximately 80 kW to 135 kW.

ROADLESS TRACTION — here is an interesting design of front axle. The drive to it is taken from a sandwich box mounted between the rear of the gearbox and the rear transmission forward to a front axle containing a conventional crown wheel and pinion and then out to a gear housing which lifts the drive line up and allows the large diameter wheels to be used without

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raising unnecessarily the centre of gravity. The tractor is equipped with differential locks on both front and rear axles. Steering brakes act only on the rear axle. The drive to the front axle is disconnectable. They offer a tractor of 85 kW.

MASSEY FERGUSON – the UK-produced 80 kW four-wheel drive uses the single pivot steer principle. The tractor is equipped with differential locks in both front and rear axle and is equipped with full braking. Steering brakes are not offered on this type of construction.

It is not the intention of the writer to argue the various merits of the different drive systems but to mention those which are produced in the UK.

The other type is the pivot steer. In this case Versatile were one of the early manufacturers to enter the agricultural market in 1966. They offer a range from 120 kW up to 220 kW, and may claim to be the only manufacturer who produced not only the axles specifically for the pivot steer but also a clever design of gearbox which forms the additional function of drop box.

Steiger is one of the major US manufacturers of pivot steer machines. They not only manufacture and sell under their own name but also manufacture four-wheel drive machines for other major tractor producers. The Steiger tractors range from approximately 125 kW to more than 340 kW. John Deere and International Harvester also offer a full range of pivot steer four-wheel drives.

In many ways the American range of four-wheel drive tractors is designed to meet conditions in North America which, although not being unique, are not widely found in the rest of the world. As far as Europe is concerned, we are unlikely to see four-wheel drive machines in any quantity above 150 kW for the present time at least.

Power gain and drive system efficiency

There is a popular misconception held by many people that four-wheel drive absorbs power, whereas, in practice in field conditions, there is a power gain over the two-wheel drive machines.

The power loss in any transmission system is, to a certain extent, dependent upon the number of gear contacts and the power transmitted through them. Some four-wheel drive systems use the same number of gear contacts, taking the drive to the front, as normal two-wheel drives would use taking the power to the rear wheels. In theory apart from the extra resistance of seals, etc, there should be no reason why there would be any difference in transmission efficiency even on hard road surfaces. This can be confirmed by looking at the OECD test results or, in the case of one machine, the Nebraska results, where a two- and four-wheel drive model with the same engine, gearbox and centre rear transmission units can be used for comparison.

As can be seen in table 1 there is no difference in the transmission efficiency when comparing pto power to maximum drawbar power either in the ballasted and unballasted condition. Although one comparison is between a medium powered two-wheel drive and four-wheel drive, the principle holds good for large four-wheel drives. These tests were carried out on a firm road surface.

Once the machines are operating in a field condition, then there is a positive gain for the four-wheel drive. In the Field Comparison of the Tractive Performance of Two- and Four-Wheel Drive Tractors carried out by the NIAE[3], it was found that when operating in good to fair conditions on level flat ground with no appreciable side slopes or hills, the four-wheel drive developed, on average, 14% more drawbar power than the two-wheel drive. No comparison tests were carried out under conditions where the two-wheel drive might have had difficulty in operating.

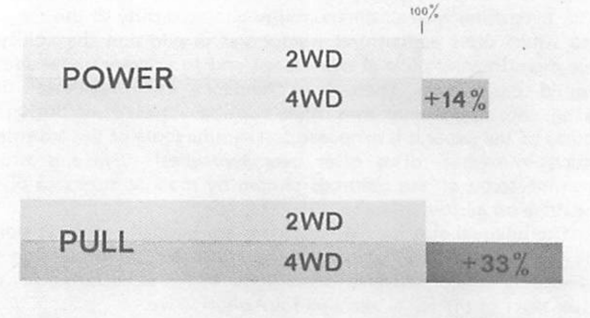
Table 1 Comparison of power efficiencies of 2-WD and 4-WD tractors on hard road surfaces

	'A' *pto power kW (hp)*	*'B'* *DBpower ballasted kW (hp)*	*'C'* *DBpower UB kW (hp)*	*B/A' %* *DBpower (B) pto power*	*'C/A' %* *DBpower (UB) pto power*
2-WD (i) OECD 539	51.8 (69.5)	43.4 (58.2)	43.9 (58.9)	84	85
4-WD (ii) OECD 283	50.6 (67.8)*	41.8 (56.0)*	43.2 (57.9)*	83	85
2-WD (viii) Nebraska 1122	101.1 (135.5)*	86.9 (116.5)*	–	86	–
4-WD (iii) OECD 490	100.8 (135.1)*	87.1 (116.7)*	88.1 (118.2)*	86	87

**original imperial test figures*

The machines in all but one of the 13 fields which were used for the comparison utilised fully mounted ploughs which would show the two-wheel drive to its maximum advantage with the load transfer from implement to the rear drive wheels. It is interesting to note that the small front-wheel drive gave approximately half the improvement of the equal wheeled machine.

Looking at the drawbar pull, it was found that the four-wheel drive averaged a pull 33% higher than that of the two-wheel drive (fig 1), again the unequal four-wheel drive giving a performance approximately half way between the two.



POWER GAIN OF 4WD OVER 2WD

Fig 1.

If, however, the use of the machine with trailed implements for top cultivation is considered, where no advantage is gained in load transfer from the implement, a much higher increase and a figure of 30–40% more drawbar power than the two-wheel drive is likely to be obtained, considerable increase in rolling resistance being found from the front wheels of the two-wheel drive.

From the continent the equal wheeled four-wheel drive has not, till now, been so prominent. But it is very interesting that one of the largest automotive manufacturing complexes in Europe has, in the past few years, entered the agricultural field with a range of four-wheel drive tractors using four equal size wheels and conventional front steer layout with linkage and pto both front and back. The MB Trac range goes from 50 kW up to approximately 95 kW and the larger units offer the interesting option of complete reversal of driver controls.

The Kramer Allrad is another equal size four-wheel drive machine being manufactured on the continent. This machine offers not only complete reversal of controls but also four-wheel steering. The current machines range from 65 kW up to approximately 90 kW.

In North America, with its large farms and often flat plain like conditions, the general four-wheel drive situation is somewhat different, the requirement being for very high powered tractors, horsepowers which, apart from a few machines in the lower range, will never be seen in Europe in any appreciable numbers. The machines can basically be divided into two types; those with four-wheel steering and those with pivot steer. The first tractor manufacturer to introduce agricultural four-wheel steeering machines

Table 2 Efficiencies of drive line and pto of 4-WD tractors

	'A' *Max engine power kW*	'B' *Max pto power kW*	'C' *Max DB power kW ballasted*	'D' *Max DB power kW unballasted*	'C/A' % *DB power engine (B)*	'D/A' % *DB power engine (UB)*	'B/A' % *Max pto max engine*
County 1164 OECD 386a (iv)	75 *	71.8*	63.5*	65.3*	85	87	96
MB Trac 1100 OECD 547 (v)	80.9	72.4	65.9	65.6	82	82	89
County 1454 OECD 490 (iii)	109.1*	100.8*	87.1*	88.2*	80	81	92
MB Trac 1300 OECD 540 (vi)	92.6	82.59	73.6	73.2	79	79	89
MF 1200 OECD 471 (vii)	78 *	68 *	59.2*	61.9*	76	79	87

* *converted from original imperial test figures*

was M-R-S, who started production in 1961; a range of machines is currently available from 120 kW up to 240 kW.

Case are now probably the leading North American manufacturer of this type of four-wheel drive configuration of four-wheel steer with rigid frame, offering models from 140 kW up to 225 kW. International Harvester also offer one machine in this configuration.

Unfortunately not many four-wheel drives have been put through OECD tests, and few companies take the optional test which gives the installed engine power. However, it is interesting to look at the tests which are available and see that an average figure for drive line efficiency in the most advantageous gear would be approximately 80%. This confirms the earlier statement that the drive line efficiencies are very similar to those of two-wheel drive.

Table 2 contains performance figures from OECD reports on four-wheel drive machines. The maximum engine power as installed is compared with the maximum drawbar power in the ballasted and unballasted condition, and the percentage transmission efficiencies from engine to drawbar calculated.

In addition the installed engine power is compared with the maximum pto power to obtain a pto drive line efficiency. It must be borne in mind that with all these comparisons, the figures used are those given in the test reports and the powers have not been corrected for variations in atmospheric conditions. However, it is noticeable that one particular machine does give an extremely high efficiency showing only a 13% loss from installed engine to drawbar in the unballasted condition.

Although it is common practice to compare pto powers with drawbar powers, the figures used in the tables show that this can be very misleading as the loss between maximum engine power and pto power varies, with different makes of tractor, from just over 4% to just under 13%. Using pto power for comparison means the least efficient pto drive system may show the most efficient ratio of pto power to drawbar power, especially with the complicated drive lines on some large four-wheel drives. Pto power should only be used for comparison where the drive line components of machines are of the same design (as used in table 1).

Weight and soil damage

Weight distribution is usually more important than total weight of a machine.

Indeed not only should the weight per wheel be considered but also the diameter and section width of the tyre.

With tandem drive machines (as all four-wheel drives are) the tandem wheels cannot be placed closely enough together for both tyres to be applying pressure to the same point. They can therefore be regarded independently. This, of course, is not the case with duals. The weight of each tyre in a pair of duals is close enough to the accompanying tyre for pressure points to be added together such that, at certain depths, the stress between the tyres is higher than that directly under the tyre[4]. Of course, duals also compact more than twice the width of that of a tandem drive system.

Weight on driving wheels is something that should always be considered for all farm operations. Perhaps it becomes most critical in final cultivation or top soil cultivation, in conditions where often the tractor is not pulling fully mounted implements but sometimes semi-mounted or trailed implements. It is in the trailed implement condition where it is easiest to make a direct comparison between the two- and four-wheel drive tractors.

Referring to the paper by Dwyer and Pearson on 'The Comparative Performance of 2- and 4-Wheel drive tractors'[3] the 13th field test comparison was on cultivated land, the tests being made pulling a crawler tractor which simulated the load of a trailed disc harrow on ploughed ground.

Table 3 shows the weights of the three tractors, the equal wheeled four-wheel drive being the heaviest machine. However, using the pulls at 20% slip and a drawbar height of 457 mm (18 in) the dynamic weights under the axles can be calculated and it can be seen in this condition that the weight under the driving wheels of the equal wheeled four-wheel drive is nearly *30%* less than that of the two-wheel drive but at the same time the four-wheel drive is pulling *80%* more.

Table 3 Weight to pull comparisons of 2-wd, unequal 4-wd and 4-wd tractors cultivated soil conditions *(Figures taken from Field Comparison) (3)*

	2-WD		*Unequal 4-WD*		*Equal 4-WD*	
	kg	*(lb)*	*kg*	*(lb)*	*kg*	*(lb)*
Tractor weight	4010	(8840)	4530	(9990)	4890	(10780)
Front axle) static	980	(2160)	1500	(3310)	2910	(6420)
Rear axle) static	3030	(6680)	3030	(6680)	1980	(4365)
Pull at 20% slip	12 kN	(2700 lbf)	16 kN	(3600 lbf)	22 kN	(4900 lbf)
Front axle) weights under draught (calc)	730	(1610)	1150	(2540)	2350	(5185)
Rear axle) weights under draught (calc)	3280	(7230)	3380	(7450)	2540	(5595)
Tractor gross weight to pull ratio	3.27 : 1		2.77 : 1		2.2 : 1	
Weight on heaviest driving axle (dyn) to pull ratio	2.68 : 1 (2.35)		2.07 : 1 (1.82)		1.4 : 1 (1)	

This illustrates in practical terms how the four-wheel drive can tread lighter than the two-wheel drive yet be capable of pulling considerably larger implements or alternatively could possibly have been reduced in weight to have even less weight under the driving wheels but still pull more.

The tractor gross weight to pull ratio for the two-wheel drive was 3.27:1 and for the equal wheeled four-wheel drive 2.2:1. However,

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taking the weight of the heaviest driving axle to pull ratio, the very interesting figures of 2.68:1 for the two-wheel drive and 1.14:1 for the four-wheel drive are obtained (the weight on the two-wheel-drive drive wheels in theory being required to be 135% more than the four-wheel drive). The unequal four-wheel drive comes between the two once again.

Relating the weight of the four-wheel drive to the equivalent weight of the two-wheel drive, we find that the former would pull approximately 49% more than the latter for the same tractor gross weight in this particular field condition. Early work done by Reed, Cooper and Reaves, in 1959, examined the effect of two-wheel and tandem drives on traction and soil compacting stress[5]. Simulated tests in soil tanks revealed that the increase in pull for the four-wheel drive over the two-wheel drive of the same weight varied from Lakeland sand – 54%, sandy loam – 43% and clay – 26%. These were all loose soil conditions.

The increase in pull of the four-wheel drive could be accounted for by several factors:–

1. The rolling resistance of the non-driven front wheels which were found to absorb up to 14% of the potential drawbar pull.
2. The second pass effect. In loose soils the first drive wheel to pass firms the soil and gives a more compact surface for the following wheel to drive on. This can increase the coefficient of traction in loose or cultivated soils by as much as 35% but at the same time Reed, Cooper and Reaves found that the second pass had little effect on increasing the stress in the soil. (It was found that using the front tractor tyre to simulate the front wheel on a conventional two-wheel drive tractor did not measurably affect the coefficient of traction on the tractor rear wheel following.)

From a weight point of view, it can be seen that generally the four-wheel drive can operate at considerably less weight per driving wheel or alternatively be capable of pulling a considerably larger implement.

It should be remembered from the viewpoint of soil damage, that it is not only weight that can cause problems with soil. The smear effect caused by wheel spin can be a very major factor. In tests carried out, it has been found that the maximum traction efficiency of a two-wheel drive occurs at approximately 20% slip; but this is not to say it is advisable from a soil point of view to work at this rate of spin. It has also been found that the four-wheel drive generally operates most efficiently nearer the figure of ten per cent slip so it can be seen that normally the weight on the drive wheels of the four-wheel drive is less than that of the two-wheel drive and the expected spin will also be less.

A practical illustration of the difference in weight on the driving axles of two- and four-wheel drive can be seen by looking at the weight tables of the tractors used in the ADAS Farm Mechanisation 21 *Study of Wheeled and Track Laying Tractors*[6]. Here six approximately 70 kW, two-wheel drives were compared with six approximately 70 kW, four-wheel drives. The average rear axle load of the two-wheel drives, as determined at the farms on which they were operating, was 3745 kg (8250 lb) whereas the average static rear axle weight of the four-wheel drives was 1620 kg (3565 lb). Making allowance for load transfer, then the dynamic rear axle loadings would probably be about 4300 kg (9500 lb) for the two-wheel drive and 2270 kg (5000 lb) for the four-wheel drive.

Tyres and tyre equipment

A feature which is characteristic of the UK produced four-wheel drives is the attention the British producers have tended to pay to tyre equipment. No matter how ideal is four-wheel drive system, if the machine is not adequately or correctly tyred, it will not perform to its full potential.

M J Dwyer (1975)[7] showed a table which gave the typical tyre equipment fitted by two-wheel and four-wheel drive manufacturers in certain horsepower classes, (table 4) also illustrating the optimum tyre equipment which, from the information that had been gained from the single wheel tester, would appear to have been the desirable tyre equipment. Generally, the four-wheel drive manufacturers have overtyred their machines and the two-wheel drive manufacturers have undertyred. The writer's company believes the philosophy of generally overtyring a tractor pays dividends both in better performance and also in overall tyre life.

The NIAE *Handbook of Agricultural Tyre Performance*[8] emphasises quite clearly that the most critical factor in the performance of any tyre is tyre pressure. It is important, if the optimum performance of a tractor is to be obtained, that it should

Table 4 Optimum and standard tyres for 2- and 4-WD tractors[7]

	Two-wheel drive			*Four-wheel drive*	
Pto power kW	*Optimum tyres*		*Tyres normally fitted (singles)*	*Optimum tyres (singles)*	*Tyres normally fitted (singles)*
	singles	*duals*			
30	13.6-36	12.4-28	12.4-28		
45	16.9-34	13.6-28	12.4-36		
60	20.8-34	16.9-34	16.9-34	13.6-36	13.6-38
75				16.9-28	16.9-34
105				18.4-34	18.4-34

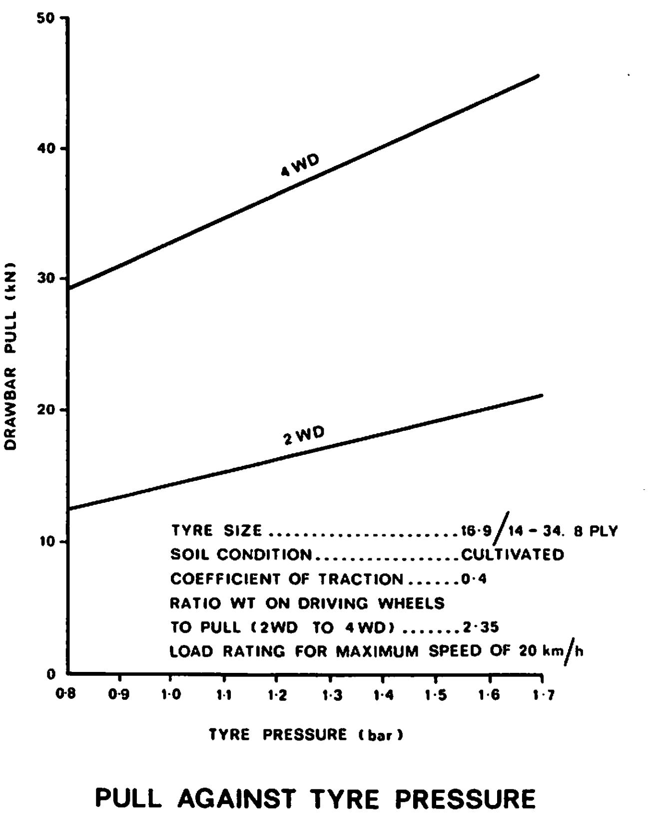
be equipped with tyres such that, in most average operations, the tyre is working at the bottom rather than the maximum of its pressure load characteristics.

Fig 2 illustrates the relationship between the drawbar pull and tyre pressures of a two-wheel drive and a four-wheel drive machine equipped with 16.9-34 tyres operating in cultivated soil. It can be seen that the two-wheel drive operating at the maximum permitted pressure and weight capacity of the tyre is giving only approximately two thirds of the pull of the four-wheel drive when it is operating at the minimum pressure and weight carrying capacity of the tyres. The drawbar pull is calculated using the maximum permitted tyre load at 20 km/h for the pressure.

A further example of the importance of tyre pressures, a subject which tractor manufacturers and tyre manufacturers have still not managed to convey fully to operators, is illustrated by investigations in the United States by Firestone and Steiger. Here tests were carried out using one of the large four-wheel drives, in this case fitted with duals all round. The first test employed 24.5-32 10-ply tyres inflated to 1.38 bar (20 lbf/in^2) all round. These tests were then repeated with the inner duals at 0.97 bar (14 lbf/in^2) and the outer duals at 0.83 bar (12 lbf/in^2) and according to the different field soil conditions, improvements in drawbar power varied from plus 7% to plus 15%. The figures are illustrated in table 5.[9]

The range of tyres available for a typical 75 kW four-wheel drive in the UK is wide and one manufacturer offers a range as standard from 12.4 section up to 23.1 section tyre. It is also possible to offer a complete range of duals, certainly on the rear and for special

Fig 2.



PULL AGAINST TYRE PRESSURE
2 WD AND 4 WD

Table 5 Increase in power by using correct tyre pressures *(Figures from ASAE[9] Paper 77 – 1518)*

Tyre configuration	*Maximum drawbar power*			*Per cent travel reduction*	
	Sod	*Disked soil*	*Clay track*	*Sod*	*Disked soil*
	kW (hp)			*(per cent)*	
24.5-32 10-ply rating R-1 bias duals Tyre Pressure 1.38 bar ($20\ lbf/in^2$) all round	123 (165)*	110 (147)*	112 (150)*	14.6	12.2
Versus					
24.5-32 10-ply rating R-1 bias duals Tyre Pressure 0.97 bar ($14\ lbf/in^2$) inside tyre 0.83 bar ($12\ lbf/in^2$) outside tyre	140 (188)*	117 (157)*	129 (173)*	12.4	11.7
Percentage power increase	(+14%)	(+7%)	(+15%)		

* *original imperial test figures*

purposes also duals on the front. For exceptional conditions, very wide section, high flotation tyres – which are approximately 1.1 m wide and have a diameter of 1.76 m operating at pressures as low as 0.25 bar, can also be used, although generally because of their high cost it is more usual to use duals. Machines with these very special low pressure tyres can operate in areas where no normal wheeled or tracked vehicle can stay on the surface.

With lighter loads per drive wheel than the average two-wheel drive, less spin and less torque per drive wheel, it is reasonable to expect that the four-wheel drive tyre costs would be consistently less than that of an equivalent two-wheel drive.

Reference to the Farm Mechanisation Studies 21[5] shows that the overall tyre cost per hectare of ploughing for the two-wheel drive for all farms was 48% higher than that of the four-wheel drive and there is a significant statement in the booklet:–

'When comparing the four-wheel drive with the large two-wheel drive tractors, the tyre costs per acre of four-wheel drive is consistently less than the two-wheel drive on all soil types'.

The development and future trends of four-wheel drive

The development of the four-wheel drive in the early 1960's came about because on the one hand the larger horsepower two-wheel drives were not capable of transmitting the full power to handle draught implements in typical UK autumn and winter conditions, and on the other hand because the crawler tractor which was slow and cumbersome and at that time generally handling only trailed implements, was inflexible and difficult to move rapidly round the farm. Furthermore in abrasive soil conditions it would give very high track running costs.

When originally designed the four-wheel drive met the requirements for a completely flexible, rubber tyred machine, capable of carrying out all the duties performed by the two-wheel drive and having also high draught capabilities suitable for handling the cultivations normally carried out by the crawler tractor. In many cases they also offered much lower maintenance costs.

Since that period we have seen development in linkage controls, two-wheel drive tractors now having not only draught control but position control and in some cases drive torque control. The radial tyre has made an impact and is now rapidly becoming the normal tyre equipment where traction and flotation are of importance. At the same time the one remaining British crawler manufacturer has certainly made tremendous efforts to retain a place in the agricultural market and we have seen improvements in track materials, track running gear and, perhaps most important, the use of fully mounted implements. Significantly perhaps UK and Italy remain almost the only European countries where the crawler has a noticeable hold on the agricultural market.

However, the four-wheel drive has also advanced during this period and with high drive line efficiencies, differential lock on all wheels and the radial tyre advantages, still competes very favourably in all agricultural conditions as being the most efficient method of carrying out the normal agricultural cultivations. It excels in certain more specialised applications such as difficult and wet conditions and on slopes and undulating ground. The four-wheel drive probably has no rivals at all on steep sidling ground where tractors are, with some caution, able to work up and down at 45° and in some cases even sideways at 45°.

County tractor working on steep land

Looking to the future, although initially we may see a rise in the sale of small front wheel or unequal four-wheel drives the author believes that the market will learn to appreciate the advantages of the equal wheeled four-wheel drive and we will see a continued development of the equal wheeled power horse which is capable of not only high draught but also of handling high pto power implements.

In addition, the market will probably see a further development of the more specialised but in many ways more flexible multi-purpose unit such as the MB trac which has pto's both front and back, linkage both front and back and with a space behind the safety cab where equipment such as fertiliser hoppers, spray tanks, etc, can be mounted. As a further alternative we may see an increase in the market for vehicles such as the County FC 1174 which still offers the ability of handling three point mounted implements at the rear of the tractor but at the same time has space for an appreciable size spraying tank and spraying boom or large fertiliser spreader or lime spreader, etc.

The four-wheel drive, with mechanical transmission, is the most efficient method so far devised of transmitting power from the engine to the ground through rubber tyres, and although manufacturers are continually investigating the possibilities of full hydrostatic transmission, it is likely to be a number of years before we see this type of transmission in full commercial use. In theory it may be the ideal form, but in practice it is yet to be proved on a world wide commercial basis.

With the ever growing awareness of the importance of timeliness, the requirement is for highly mobile machines giving a high performance over a wide range of conditions and a variety of terrain, capable of high speed light pulls and of handling heavy draught implements. High pto power is also essential. At the same time the machine must be capable of treading lightly over the ground and doing the minimum of damage wth the maximum driver comfort.

The machine that meets the above requirements is the equal wheeled four-wheel drive.

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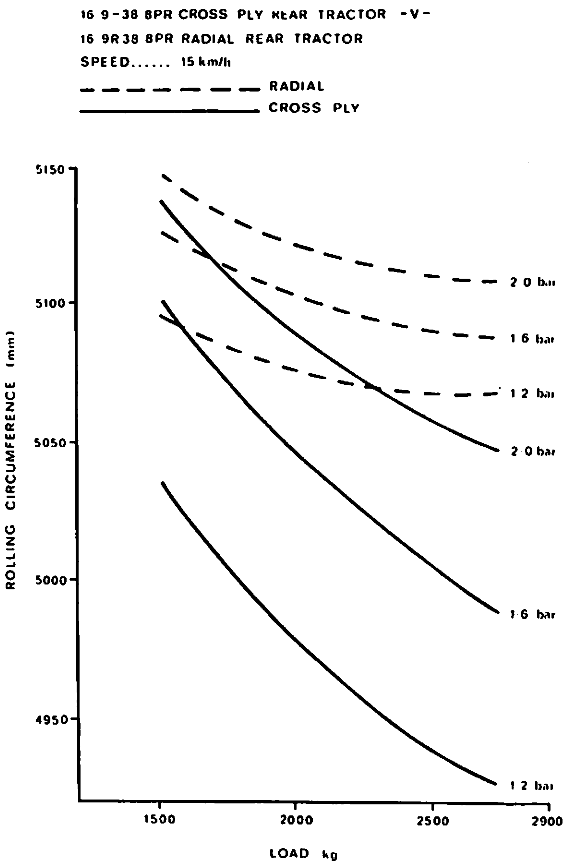

ROLLING CIRCUMFERENCE
v
LOAD & INFLATION PRESSURE

Fig 3

Appendix

During the course of the paper, mention has been made of radial tyres. All UK four-wheel drive manufacturers now offer radial tyres as a standard option and a high proportion of customers are stipulating radials as original equipment. The writer feels that the advantages to the performance of the machine would be worth listing:—

1. **Traction**
   The NIAE at Silsoe have found, in comparative performance experiments, that the radial tyre on average gives between five per cent and eight per cent higher pull than the cross ply at 20% slip. The advantage in traction of the radial over cross ply reduces as slip increases so at the lower rate of slip for a four-wheel drive, the advantage is likely to be greater. Perhaps rather than considering the increased pull obtained, less slip at the same pull may be the most important factor.

2. **Wear**
   Discounting accidental damage and damage through negligence, the radial tyre will give a longer life. The amount will, of course, vary greatly with operating conditions but an increase in life from 50 to 150% or even more might be expected in many cases.

3. **Ride**
   This is a difficult point to quantify but most operators comment favourably on the improvement gained from the flexible side walls.

4. **Flotation**
   Large wheeled four-wheel drives offer excellent flotation but the increased area of the footprint of the radial tyre improves this even more. One manufacturer claims an increase in footprint area of 10—13%; another 17½% with a 16.9-34.

   Varitions in figures will occur due to the different methods of measuring the footprint area, but without doubt the radial reduces ground pressure. In fact, it brings the footprint pressure down almost to the actual tyre pressure, whereas the cross ply footprint pressure is generally considered to be approximately 0.14 bar (2 lbf/in^2) above the tyre pressure.

5. **Rolling circumference**
   Although it is often assumed that the rolling circumference of a wheel is 2π times the loaded radius, this is not accurate. Practically a figure of two or three per cent more is likely to be obtained. In fact, half the tyre diameter plus the loaded radius times π gives a more accurate approximation of the rolling circumference for cross ply tyres. However, radial ply tyres, with their flexible side walls and stiff circumferential tread band, (the tread band can expand very little and neither can it shrink) give very nearly a constant circumferential speed.

   One manufacturer quotes a variation of 0.5% in the rolling circumference from the full load to the half load condition without changing the tyre pressure. The cross ply tyre will show three or four times more variation under similar load or pressure conditions than the radial and this is clearly illustrated in fig 3. With four-wheel drive this almost constant rolling circumference can mean a considerable reduction in possible variations between front and rear drive speed especially when the work cycle may call for considerable variations in axle loadings. The result of this is less wear and less loss of power. The graph shows the small variations for radial tyres and it can be seen that from a pressure of 2 bar and small load, to a pressure of 1.2 bar and an overload, there is only a 1.5% variation in the rolling circumference. Something like three times the variation is found with the cross ply.

   In four-wheel drives where both front and rear wheels are driven at the same speed and under some operations where considerable variations in load are found during the working cycle, then radial ply tyres can show a very distinct advantage.

Forestry tractors

Airlie Bruce Jones

Summary

THE development is reviewed of specialised forestry machinery, based upon the requirements of the industry. Operational considerations of the forestry transport machine are drawn to the attention of the machine designer.

Part 1 – Development and application of forest machines

Introduction

"A FOREST is a large uncultivated tract of land more or less covered with trees."

This dictionary definition in part explains the primitive and rugged nature of the forest environment.

"Forestry is the art of cultivating and managing forests."

In today's world forestry is mainly practised on land which is unsuited for agriculture or where the cost of converting land to agricultural use would be uneconomic.

Although forestry has been practised for centuries, only during the last 60 years has cultivation really been a practical proposition and even now, due to terrain conditions, the scope is limited.

It is perhaps because of the English lack of understanding or appreciation of the forest, except in the conservation sense, that the commonly accepted international term for the working of round wood in the forest – logging – does not appear at all in some dictionaries, and if it did, it would almost certainly refer to cutting firewood.

The forest

The forest from a designers point of view is a good example of an engineers nightmare. Every parameter which can be identified has to have the winter/summer, snow, tree size and terrain factors added to it.

Anyone who has considered the problems of 'on field' agricultural cultivations or processing will be well aware of the effect of weather, side slopes and variable soil conditions on normal agricultural field machinery. The same problems exist in the forest with some additional considerations. For instance, although some forest land could be classified as suitable for agricultural cultivation, most of it would be totally uneconomic due to difficulties inherent in the site. Slopes up to 40°, peat and drainage problems, surface rock and boulders are typical of normal forest terrains.

Apart from the planting and weeding of young trees, forestry work is not seasonal and continues throughout the year. The economics of the industry dictate that work must continue regardless of weather conditions. This means that equipment must be designed to work continuously and economically under both summer and winter conditions.

Scale and the woodsman

Scale varies enormously. Forest concessions are granted by governments in some parts of the world by the 100 000 acres. In Europe, with increasing environmental control and sub-division of land ownership, working areas of under 10 acres are normal.

Capital is limited – a high machine utilisation is essential. Specialist machines able to work only half the year or unable to perform a secondary productive function in steep terrain or winter weather conditions have limited application. The equivalent of a grain combine or silage harvester used for three to six weeks in the year has little place in today's forest industry.

The great opportunity in the forest has always been for the intelligent worker who could handle timber with virtually no equipment at all. The natural shape of the log, gravity, water and some ropes, when combined with a skilled logger, has always been sufficient to work the woods. The addition of horses, oxen or mules would easily enable five and ten ton loads to be managed.

Work in the forest is tough and difficult to control. Men can be working 40 miles from the nearest supervisor and anything can happen at that range. As a result a high proportion of *efficient* operations are run using variations of a contractor system, where the man on the job is also the boss. If these working contractors are to be able to afford the machines they use, the machines have to be both reasonably simple and modestly priced.

For the manager controlling machines in the forest, the message is clear – machines must be easily moved from site to site, simple enough to be largely 'maintainable on the spot' and flexible enough to do more than one job.

Prime movers

The arrival of steam, a source of power for winches which made reliance on water for transport less critical. Logging activities then penetrated further from water courses. Railways in the forest, cheaper to instal in the days before the bulldozer, further outmoded water and man-made skid trails. Steam winching provided the means of defying gravity and working uphill. Spar trees were rigged, skylines raised and an overhead railway system, unaffected by the surface or gradient of the forest, became a reality. The abundance of fuel wood ensured a long and successful life for steam in the forest and round the stationary steam engine grew a wealth of knowledge and techniques. These techniques are still in use today in areas of the world where modern tyres or tracks don't pay.

One of the earliest forest uses of the internal combustion engine was almost certainly on haulage where some of Mr Ford's Model T's were converted for running on the rails. The arrival of tractors made possible a more mobile form of winch, as well as the chance to tow or skid trees on easy terrain, directly behind the tractor to a road or loading point.

'Man and horse' power

At the same time as this tractor development was taking place, animal transport of smaller trees was continuing as it must have done since the early days of domestication. One horse with simple harness and a chain attached to the log could transport ½-ton on the flat and up to 1-ton downhill. In many countries today, and in the UK until the mid '60's, most small trees or thinnings were handled by the two original forestry prime movers – 'man and horse'.

Even today, the economics of man and horse are passable if ground is steep and the trees are not too heavy. The problem is one of looking after the horse at the weekend in an isolated forest area.

Logging progressed during the 20's and 30's from steam to the agricultural tractor of various types for winch powering or haulage.

Crawlers

The development of the crawler increased skidding payload and made possible the installation of cheap low grade roads on which trucks could start to move into the forest, thus replacing the railways.

After the 1914–18 war, planting in the UK increased to replace the ravages of war and to establish a strategic reserve for the future.

Research into forest establishment techniques showed what major advantages could be gained from cultivations and drainage. Crawlers used for road making were adapted to work on the extremes of soft or steep ground towing ploughs, capable of working all but the rockiest sites.

Each logging site with its numerous variations of tree size, terrain and scale presents an individual problem for management. An economic balance between the cost of driving in a road for landing and loading the timber, set against the cost of skidding or winching timber extra distances from stump, is necessarily under continuous

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Airlie Bruce Jones, James Jones Ltd.

Paper presented at the Autumn National Conference of The Institution of Agricultural Engineers, held at The Lorch Foundation, Lane End, nr High Wycombe, Bucks, on Tuesday 10 October 1978, when the subject was Specialised Prime Movers in Agriculture.

review. The relatively slow speed of the crawler under timber hauling conditions ensured that the logging industry was continually searching for something faster.

Ex WD vehicles

The second world war produced the answer: an abundance of government 4–6 wheel drive trucks at knockdown prices with numerous shortcomings but two real assets – price and simplicity.

Possibly the greatest influence on logging machines today stems from 'the old army lorry'. Its success as a general purpose tool is worth thinking about. It offered:–

1. Power cheaply,
2. A winch, which could be used for hauling of timber to a road, or as a crane to perform a loading operation.
3. A small load carrying capacity cross-country or larger one on roads or tracks,
4. A mobile self-propelled platform on which specialised equipment such as cableway winches could be mounted.

Forest machines

The last 20 years have seen the serious development of machines purpose built for forestry. In contrast to agriculture, where the tractor appears to have had a reasonably stable general design for many years, forestry tractors are going through a period of proliferation, a perhaps natural effect of the enormous variation of forest sites and conditions and recent attempts to mechanise them.

Some of the more conspicuous features which can be seen on present day machines include:–

Low ground pressure tyring.
4–6 wheel drive.
Removable full tracks and half tracks.
Articulated axle assemblies controlled by the operator to give a levelling effect.
Front or rear wheel steer; articulated frame steer; skid steer; 4-wheel steer.
Hydrostatic transmission.
Telescopic hydraulic tool carrier arms.
Reversible control positions to enable machines to return quickly by same route when turning areas are restricted.
Increasing hydraulic capacity to power ancillary equipment.
Radio controlled functions to operate equipment where the man is working in the forest on his feet.

At the same time a number of small machines controlled by a walking man, worked in much the same way as a horse, have appeared and snow-mobiles, vineyard tractors and garden machinery tractors, not to mention balloons, helicopters and hovercraft, are all "having a go".

The forest industry requires a range of simple cheap base units with many of the characteristics of the 'old army lorry'. It must be tough enough to stand five years in the forest (equivalent to 15 years on the farm) and possess sufficient design flexibility to allow the specialist equipment manufacturer or logger to use it to transport and power his growing armoury of specialised tools both 'in forest' and on the road.

Part II – Some technical considerations for the modern forestry transport machine

Horsepower and machine size

First, big is not beautiful in the forest. Large machine weight, which tends to be related directly to hp, causes ground damage; the weight cannot be distributed horizontally because the machine would be too wide for the forest, so the centre of gravity tends to rise to an unacceptable level. Of course, there are wide open flat places where enormous machines can operate but these have limited application in most European and many other situations throughout the world. In USA and Canada one can see 100 t 300 kW machines based on second-hand Vietnam tank chassis perform useful tasks. Economic operation is difficult, however, when large repairs become necessary.

Confusion is added to the field by the needs of some large forest countries with extreme climatic conditions, or natural forests in sparsely populated areas. These countries – Sweden, Canada, Russia for instance – with terrible winters, two or three daylight hours, but huge timber resources, can justify machinery whose sole purpose is to maximise the output of an operator in otherwise impossible working conditions. Two hundred kilowatts is certainly needed for passing fully loaded through two metres of snow in thirty or forty degrees of frost.

A £100 000 machine can look cheap as an investment when related to the extra foreign exchange generated if, instead of a five months' logging season, operators are able to work for 11 months on two shifts basis.

Consider, however, the more normal conditions where snow is not a serious factor, temperatures in daylight hours are perfectly bearable and above all men or women are available to perform the traditional tasks of working the timber in the forest all year round.

Machines can then be simpler, less automated and the operator does not require to be insulated from the elements purely to ensure his survival. In fact, excellent economies can be experienced when the equipment is simple enough for the good operator to use it to complement his own forest skills. When forestry is defined as cultivation and management of forests, the thinning – a cultivation activity – is today one of the most, if not the most, important activity. For this, anything more than 90 kW has so far proved an embarrassment.

Speed

In forest travelling speeds are normally low – fast driving is uncomfortable and tends to accentuate the holes and bumps on the surface when more than one pass is made over it. Low gears, giving speeds ranging from 1–8 km/h, give excellent control for in forest working. On forest tracks when fully laden, top speeds of 11–16 km/h are fast enough. On the road between sites up to 32 km/h is useful. Torque convertors and powershift gearboxes are adopted in the larger hp range but add to both price and complexity. Many forest operators opt for conventional clutch gearbox configuration, concentrate on driver training and settle for 'self maintenance' – a valuable contribution to 'up time' in a field situation.

Steering

Steering arrangements depend essentially on the machine designs involved. Skid steering, front or rear wheel, 4-wheel steer and articulated frame all are used and sometimes more than one system when long loads or tight corners are involved. Machine purposes differ and where steep ground or a rigid machinery mounting platform is required, the articulated frame can have disadvantages. Equally, wheel steering is more susceptible to damage if not constructed with forestry usage in mind.

Tyres and wheels

At the point of contact with the land the forest machine requires a low ground pressure tyring to cope with winter or soft ground conditions. Larger diameter tyres help here both in their ability to climb over obstacles and in spreading load. Wider tyres or doubles are more vulnerable to accidental damage and make the overall vehicle too wide for the space available for manoeuvre within the forest. A common compromise is to use smaller wheel sizes but to couple axles together by means of flexible steel track belts.

The flexibility inherent in a removable track system is just the type of development which makes sense on the logging scene.

Drive

Flexible tracks, 4- or 6-wheel drive, depending on machine length, are virtually essential for inforest work. Ground clearance above 0.5 m is an objective to be striven for and even then soft ground plus a stump or a hidden boulder create obstacles which 'hang up' one end or other of the machine. The other set of driven wheels then become the only thing which can move the machine on over the obstacle. One of the shortcomings of the traditional crawler in these circumstances, with its smooth flat underside, is that although it can grip a lot of ground, one stump in the middle could leave it high and dry. The forest machine with two or more axles driving and a higher clearance between the axles than under them gives a better performance.

Final drive reductions which combine a ground clearance improvement for the half shaft casing are obviously valuable if constructed strongly enough. Unfortuntely, most of them are being designed for the smaller wheel diameter of more conventional industrial applications used in the larger industrial construction market.

Axles

Axle loading tends to be higher than most other comparable activities. Consider the loading on the rear axle of a timber skidding machine working uphill with wheel chains fitted, when one rear wheel grips a tree stump and the other soft ground. With differential locked most of the available engine torque is transmitted to the wheel with a grip on the stump. Going uphill fully laden the driver may well be in bottom/bottom and forward movement is maintained, not by normal frictional resistance between tyres and soil equally divided by the numbers of wheels, but by the rack and pinion effect of a wheel chain spike digging two inches into a resilient block of wood anchored firmly to the ground by a root system.

NB After the tree has been cut the stump and root system left provides a useful, and sometimes the only, means of supporting the traffic in the forest.

Brakes

Unsealed drum brakes on the end of the axles are a liability for machines in winter. Some soils produce a slurry of mud up to 70 cm deep which gathers on access tracks or landings (points where timber processing takes place). Drum brakes do not perform well under these conditions. Normally, however, extreme conditions for brake usage, ie hills, tend to be better drained and on wet flat sites brakes are barely required, except for winching. Correct use of gears and front blades provide practical alternatives but totally enclosed brake systems are the most effective.

Chassis — loading

Apart from axle and transmission overloads, the chassis can also expect substantial punishment coming from strains transferred from one diagonal wheel to the other when travelling over rocks and stumps. Although skidding, hauling or dragging are the normal descriptions given to the forest machines work, in practice a superimposed load is the norm. This load is obviously variable but it is not unrealistic to anticipate 'payloads' by the operator of up to 50% over normal maximum rating. A 'load' can be varied substantially by the unit length, eg logs 6 m long instead of 4½ m immediately increase the load weight by one third. Furthermore, depending on species and location, wood density can vary from 0.07 to 0.11 m^3/t. So accidental misuse and even intentional abuse of machinery must be anticipated.

Cabs and controls

Operations in the forest on a European scale involve the operator in mounting and dismounting regularly from his cabin. For this reason some of the equipment he uses on the forest floor is being controlled by radio. Access is, therefore, important. Also vital is all round visibility and space within the cab to reverse the seat position to operate controls for equipment working to the rear.

This space at knee level must be achieved without increasing excessively the width at head height, otherwise on side slopes the cab will obstruct passage between trees when working in thinnings. As full engine speed is seldom a requirement during forest work, noise levels during normal operations are relatively low.

Controls for tools and equipment should work on the simplest possible principles and the use of mixed control systems, eg electro hydraulic, should be avoided where possible if maintenance downtime is to be minimised. Remember the operator who topped up his hydraulic oil tank with the only container he could find — a used cement bag — was almost certainly a logger.

Today

Timber handling systems have developed on three distinct lines:—

1. For logging large trees.
2. For logging trees which are individually too small to constitute a load and therefore require assembling into a bundle.
3. Cableway systems to work where wheeled or tracked vehicles cannot go.

Most forestry countries in the world have forest engineering industries producing machines to suit their own local conditions.

Specialised tractors (skidders) equipped with winches and grapples have been developed to skid long trees with about half the weight suspended above the ground to reduce friction. Other machines (forwarders) with the capacity to lift shorter timber from the forest floor and carry it on wheels, are in common use on moderate terrain.

Agricultural tractors are used for limited forest road haulage activities and for powering static equipment. Use 'in forest' for logging is best confined to part time forester/farmer activities, unless substantial conversion and reinforcement to the tractor's structure has taken place.

For areas too rough or steep for wheels, yarders, or cableway winches with steel towers up to 30 m high, for giving lift to the logs, are in use.

The current development objective is to combine transportation machines with tree processing activities such as felling, cross-cutting, debranching or loading, without creating mechanical white elephants.

The range of machines available today on the market originate from one of two design approaches. The first makes use of standard engine/gearbox/axle assemblies from existing agricultural or industial tractor manufacturers and converts or modifies these units to suit forest operating conditions.

The alternative approach is to design from scratch a totally specialised machine for the job.

As power increases over 90 kW the special design becomes more essential, because the standard mass-produced components may not be available. The market for these larger machines being relatively smaller, they tend to be disproportionately expensive.

Conclusion

Forest terrain and the trees which grow on it vary enormously. Mechanised operations in forestry seldom make economic sense unless they are designed to suit the scale of operations, the actual terrain and the trees to be handled.

Agricultural, civil engineering and crawler tractors are all used in forestry but the arduous conditions of 'in forest' transport usefully require more specialised machines and many different specifications are built to cope with local conditions.

Up to 90 kW extensive use is made of mass-produced tractor components to simplify design and keep costs down.

Purpose-made higher horsepower machines are also produced but local terrain, forestry practice and economics often limit the areas where such machines can be applied effectively.

The future lies in the development of simple equipment at a price the forester can afford, which can be used to reduce or eliminate the hand work still normal today.

Crawler tractors

Hugh F W Flatters

Summary

THE place of the crawler tractor in agriculture is reviewed in the light of recent technological developments. Minimal soil compaction and the ability to work land which would otherwise not support tractor work are discussed, as is a need for improvement in track materials.

Introduction

THE first tracked vehicle was patented by a Yorkshireman — Sir George Cayley — in 1836. He worked very closely with John Fowler who founded his company in Leeds in 1848 and who was one of the leading pioneers of agricultural mechanisation.

He converted his ploughing engines to track pads and introduced the 'Snaketrac' which was possibly the first full tracked steam tractor.

Although the Holt Company, ultimately to become the Caterpillar Tractor Company, has become the largest world manufacturer of these machines, it is interesting to record that Fowler produced the first diesel engined crawler tractor. However, as the theme of the Conference illustrates, the crawler tractor is enveloped as a 'specialised prime mover in agriculture' — although many farmers throughout the world would not agree with the word 'specialised'.

Since the beginning of mechanisation in farming, the selection of agricultural tractors has been the subject of continuous debate. The complexities of initial and operating cost, soil and climatic conditions, the economics of application and effective utilisation always generate serious discussion. Obviously, when speaking of crawlers, these can only be bracketed with the larger powered two wheeled and four wheeled drive machines, both from initial and operating costs and, for that matter, work output.

From the outset, it was always recognised that, in heavy going the crawler tractor possessed superior tractive powers but, initially, this advantage was offset by problems associated with track life. This has been changed by major advances in engineering technology.

Today, technological advance has not only improved the base materials used in track component manufacture, it has also brought about significant improvements in gas carburisation — giving 'guts' to the tracks (the hard core centre and base strength) — and induction hardening, which provides the final hard skin to give maximum life to all track chain and track roller components.

The time consuming daily and, in severe conditions, twice daily chore of lubricating track rollers and idlers has been totally eliminated by the introduction of 'lifespan' lubricated rollers and idlers. Accepting that crawler tractors are frequently required to operate in conditions of mud and filth where no two- or four-wheeled drive unit could move, it is readily understandable that only the most conscientious operator would carry out the essential lubrication of the track components.

Today's components and design principles have completely overcome the problem and it is now necessary only to check periodically that the correct amount of lubricant is present.

Even more damaging to running track than abrasive soil conditions is maladjustment. A particularly tight chain can accelerate pin, bush and sprocket wear far more rapidly than the most abrasive soil elements. Additionally, overloading can be imposed on the final drive unit with consequent damage. The one-time 'fitter's nightmare' of track adjustment has been overcome by the introduction of hydraulis adjustment as a standard fitment.

These developments, introduced over recent years, are prime factors in effecting considerable reductions in crawler tractor operating costs, a feature that cost-conscious farmers have been quick to appreciate.

In application, the superiority of the crawler tractor as a machine for heavy cultivations — large ploughs, large harrows, sub-soiling, mole draining, etc — is irrefutable. In this capacity, the three major advantages of the crawler tractor are immediately apparent:

1. Greater, more effective use of engine horsepower.
2. Larger drawbar pulls.
3. Better area of ground contact resulting in better grip and increased output, particularly in difficult soil conditions.

One frequently overlooked, but nonetheless major advantage, is the considerable facility of low ground pressure and the 'flotation' advantages for all seed bed preparation and drilling. As mechanisation increases, so new, larger and heavier wheeled machines are introduced for the planting and harvesting of an ever-increasing range of crops. This results in the more frequent passage over the soil of large wheeled machines, incurring serious soil compaction. This must inevitably result in soil consolidation to the point where land has difficulty either in breathing or in draining properly, with disastrous effects on crop yields.

A criticism frequently levelled at earlier crawler tractors was their lack of versatility, leading to restrictions in machine utilisation. Until recently they were obliged to operate with trailed equipment. Bearing in mind that frequently, crawler tractors have to contend with conditions that render wheeled tractors inoperable, situations have arisen where, whilst the crawler could operate effectively, the trailed equipment could not.

Additionally, today's operators are fully hydraulically orientated and to expect them to operate large equipment by literally 'pulling a piece of string' was virtually pushing sophisticated tractors back into the early 1900's.

This criticism was completely and dramatically nullified by the introduction of the first ever fully versatile hydraulic three-point linkage for crawler tractors.

Because the crawler operates on top of the land, the design of a successful three-point hydraulic linkage was beset with special problems and the two main areas of difficulty were off-setting ploughs and steering. These were completely overcome by Marshall-Fowler — the first company in the world to produce a linkage of this type — and this has resulted in a great expansion of the crawler tractor's versatility and, therefore, its utilisation.

Crawler tractors are now not only classified as heavy cultivation machines — although this remains their primary function — but they can also be fitted with all types of central draught equipment. In addition, larger ploughs, cultivators, chisel ploughs, etc, can now be pulled more effectively as mounted, rather than trailed equipment, thus giving far greater outputs from the base machine.

It has been suggested that introduction of three-point hydraulic linkage has increased crawler tractor utilisation potential by at least 20%.

On the question of utilisation and, for that matter, also embodying a further major point of criticism against crawler tractors — track costs when compared to the cost of tyres — it is interesting to record some of the findings in the *Wheeled and Tracklaying Tractors ADAS Farm Mechanisation Studies, No 21.*

"The large two wheel drive tractors seem ideally suited to working long hours on light soils but those on heavy farms were used for less than half the number of hours."

Still referring to the use of large two wheel drive tractors, comment is made:—

"The problem of traction on heavy land is clearly shown by the drastically shortened period of use"

It should also be noted that when these tests were undertaken, the autumns of the two years in question were drier than average.

The following reference was made to four-wheel drive:—

"The more specialised configuration of this tractor dictates that it should only be used for those jobs which it is ideally suited. In this sample, these tractors spent over 80 per cent of their time on ploughing and heavy cultivations. As has been mentioned earlier, improved tractive ability on heavy land is suggested from the fact that not only did the tractors work longer hours than the two wheel drive tractors but they also recorded a higher average rate of work when ploughing"

Hugh F W Flatters, formerly of Aveling Barford International Ltd.

Paper presented at the Autumn National Conference of The Institution of Agricultural Engineers, held at The Lorch Foundation, Lane End, nr High Wycombe, Bucks, on Tuesday 10 October 1978, when the subject was Specialised Prime Movers in Agriculture.

However, on crawler tractors:

"The indications are that they are likely to be able to record the best annual utilisation figures for heavy land farms compared with the other tractors"

To those of you who have been indoctrinated against crawler tractors for various reasons, the comments relating to the costs of tyres and tracks may be even more remarkable, namely:

"The fact that track costs on heavy land were the lowest by a margin of some 20% will surprise many people. It is often considered that a tracklayer is a necessary evil. The implication has always been that tracks are more expensive to maintain than tyres. These results suggest that as well as being better from the point of view of traction and compaction, tracks are also cheaper"

To add even greater strength to the crawler tractor story, the question of power utilisation was also investigated in considerable depth which showed that tracklaying tractors were operated most efficiently.

"An average PUP (Power Utilisation Percentage) of 77% for an extended period of ploughing suggested that the operators of these machines achieved an even better figure for the bulk of the work, bearing in mind the time taken at headlands, etc, at reduced governor settings. The superior tractive ability of a four-wheel drive design might be expected to give a higher PUP than a two-wheel drive tractor of similar size. In this study, this was not the case — PUP figures for ploughing for the four-wheel drive and two-wheel drive were 57 and 66 respectively.

The PUP for the 70 hp two-wheel drive tractors was very disappointing, averaging only 43 for ploughing."

In fact, the concluding paragraph of this Study reads:

"With increasing concern for the effect of heavy wheeled tractors on soil structure, this new information on tyre and track costs is likely to lead to renewed interest in use of tracklayers on heavy land in the future."

Soil compaction has long been a subject of considerable discussion and study and essentially due to larger and heavier equipment being used today in tillage, weed control and harvesting, it is now more critical than ever.

Equally, attempts to overcome soil compaction and create favourable environments for root development and consequently better yields, have become extremely costly.

The average pressure imposed by the more popular sized crawler tractors is approximately 44 kN/m^2 (6.4 lb/m^2). The average length of track on the ground being some 188 cm (74 in) and when fitted with 40.6 cm (16 in) track plates, a ground contact area of 15 200 cm^2 (2360 in^2) is obtained.

Comparable figures for a wheeled tractor would be from two to four times greater. When crawler tractors have been operated this has resulted in at least 30% less soil resistance to a depth of over 46 cm in the soil.

Also, it should be remembered that generally soil moisture is at a level which is the best time for working the fields when it also allows easier compaction. Additionally, the pressure which wheels exert is not entirely vertical but part of that pressure is absorbed laterally as it is transmitted deeper into the soil and naturally a 'fan' effect is created.

Compaction is an extremely serious problem and many studies have and are being undertaken. From all these, the general philosophy is that we are cultivating the land solid — not only with larger and heavier wheeled tractors but with all the mechanised traffic which is necessary in present day farming.

Finally, a little glance to the future. Crawler tractors, as with many other items of agricultural equipment, will grow in power. Naturally, to use that power effectively, weight will have to increase but constraints will have to be imposed in this area. I feel that the farmer is nearing the limit as to the capital investments he can make in machinery purchases based on the returns he is getting for his produce, particularly in view of the vast inflationary spiral we have experienced during the past few years.

In pure economic terms many items of agricultural equipment are completely uneconomic in the concepts of any other form of industry but they have to be purchased of necessity. Therefore, manufacturers have to look to the future to give greater versatility to machines of the future and the crawler tractor is no exception.

As a result, apart from more specialist machines, the weight has to be retained within reasonable limits to retain acceptably low pressures to ensure the continuance of spring cultivations, in addition to the main workload of post-harvest cultivations.

Transmissions could well prove to be a prime area of change. Many comments are continually made as to why mechanical drive transmissions are retained for agricultural applications whereas the construction equipment machines employ more sophisticated power shift.

The reason is that in agriculture there is a constant loading application whereas in bulldozing the loading is only intermittent. At all times in agriculture a high drawbar pull is necessary and, without doubt, the stresses and strains imposed on transmissions and final drives are far greater than on bulldozing applications. Additionally, mechanical transmission is still far more efficient than hydrokinetic and for continuous constant loading a stage could well be reached where the oil could reach boiling point in the torque converter.

Nevertheless, I firmly believe hydrostatic transmissions will ultimately be introduced and, even though their efficiency would not be as great as a mechanical transmission, the advantages of flexibility of speeds and greater manoeuvrability outweigh these — providing the costs are not prohibitive.

Obviously, driver comfort will continue to improve, particularly in the area of reduced noise levels.

Perhaps the largest single area for development is the track running gear. Lack of mobility is the biggest single restriction of the crawler tractor. Indeed, it might be said that if a material could be developed which had the properties of an existing track but also allowed the mobility and speed of a wheeled tractor, the latter would not be purchased.

As was stated in the early part of this paper, many new developments have been introduced over recent years and, more recently, sealed and, for that matter, lubricated tracks have appeared on the market — both of which have doubtful qualities — but we are still searching for a new type of track material.

As the world population increases, it is imperative that good soil structures are preserved to obtain maximum crop yields to meet the ever growing hunger and the crawler tractor will preserve that soil structure far better than any other form of motive power which is known today.

Advertisement bookings and copy for the Spring Issue should be sent in by 3 January 1979.

Specialised prime movers in agriculture

Edited summary of discussion

J Kilgour (NCAE) commenting on Mr Bennett's paper *Vineyard and Orchard Tractors*, asked if there was a UK demand for such tractors and whether the markets could be extended into the new types of hedgerow orchards or other specialised situations such as where rice and sugar cane were intercropped. He also enquired whether it would be worth encouraging the DoI to provide money for the exploration of new markets.

John Bennett explained that there was some UK demand for narrow tractors, but the main requirements for orchards was a low streamlined machine. Further, he thought that it would be inappropriate for government money to be allocated for the exploration of new markets since all such tractors were made on the continent of Europe.

T C D Manby (NIAE) felt that perhaps Mr Bennett had dismissed straddle machines rather too easily. He felt such machines had a very definite place in the mechanical harvesting systems for grapes and, therefore, there may be a continuing demand for them.

Mr Bennett said that grape combines were available and were, in fact, straddle machines but that they were specialist self-propelled harvesting machines that were used only for bulk produced wines. The production of high quality wines required selected harvesting by hand. He added that the straddle machines would cost something like twice that of narrow tractors and that they were not particularly suited to much of the steep ground on which vineyards were planted.

P Jaggard (County Commercial Cars) commenting on Lamar Williams' paper on *High Clearance Tractors* said that in his view a very strong full torque tractor was required, particularly for cane production, and that front axles were especially vulnerable.

The speaker agreed with this view and said that, although it was possible to alter the configuration of high clearance tractors in the John Deere range back to normal clearance this was very rarely done by farmers.

J Matthews (NIAE), asked if small articulated 4-wheel drive vineyard tractors had reached their full potential.

Mr Bennett replied that in general the hp was too low and the cost was high since they were not based on a high volume standard tractor.

V Crockford (Roadless Traction) commented on the definitions used by Mr David Tapp in his paper on *Large Four Wheel Drive Tractors*. He preferred all-wheel drive (four equal sized driven wheels), four-wheel drive (two large and two small wheels all driven) and front wheel assist (occasional four-wheel drive). He expressed the opinion that the unequal wheel tractors may be better up to 100 hp and equal four-wheel drives over that figure.

R Ross (Forestry Commission), picking up the theme of Mr Airlie Bruce Jones' paper on *Forestry Tractors* said that there was a great need to benefit from the mass produced machines built for agricultural purposes in the small forestry market. He also echoed Mr Jones' plea for engineers to produce strong and unsophisticated machinery and systems for forestry.

J Matthews commenting on Mr Flatters' paper on *Crawler Tractors* asked if there were likely to be any developments in the area of rubber tracks to improve road mobility and wondered whether track vehicles would be superseded by multi-wheel vehicles on very low pressure flotation tyres. He also mentioned the development of high speed tracks in the USA. It was pointed out that in extreme conditions of gradient and roughness, in both forest and vineyard, it was still necessary to use tracked vehicles. Also, that the use of very low ground pressure vehicles could increase the pool of land which was of low commercial value for forest development.

A Gee Clough (NIAE) commenting on Mr David Tapp's paper, said that in any comparison of 2-wheel and 4-wheel drive tractors the degree of ballasting was extremely important, that significant increases in performance in 2-wheel drive tractors had been found when using larger than standard tyres correctly ballasted and that the performance was obtainable at much less cost in a 2-wheel drive tractor.

David Tapp said he thought that suitable tyres would not be available for 2-wheel drive tractors to equal the 4-wheel drive performance.

G May (Farmer, Hampshire) enquired whether front mounted linkages and pto shafts were to become available.

Mr Bennett said that they were common on the continent as a factory or dealership option and Ferranti were now marketing such units in the UK. Great interest was being shown in these linkages and the manufacturers were pleased with sales.

Mr Matthews pointed out that a British standard was in an advanced stage of preparation and that it was extremely important that such a standard should be adhered to if front linkages were to be widely used.

Mr May pointed out that he would like to use a front linkage for buck raking, mowing and perhaps forage harvesting in his silage making operations.

T Sherwen (Consultant) asked how changes in rolling circumference was dealt with on 4-wheel drive tractors in which the wheels were differently loaded.

Mr Tapp said that this was not normally a major problem since it only required one or two per cent slip to absorb the differences and that radial tyres were helping with many problems in this direction since their rolling circumference was less variable than cross-ply tyres.

In reply to a question from the chairman, **Mr Tapp** said that radial tyres had a much better life when used in either field or road conditions. However, more driver training was required to avoid damage to tyres through carelessness or running at incorrect inflation pressure.

Agricultural drainage in England and Wales

A D Bailey

Summary

THE paper reviews the whole aspect of field drainage in England and Wales, and in so doing, can only touch on the major features in an illustrative way. In simplifying problems for ease of presentation there is a danger of considerably understating the difficulties and the efforts, both past and present, to resolve them. Sub-surface drainage has been practised in England and Wales for over 100 years and yet there remain many areas requiring considerable research and development; not the least is the drainage of heavy clay soils.

Historical background

THE earliest significant land drainage works were carried out by the Romans in the English Fens, only to suffer decay and destruction in the Anglo Saxon period. In the medieval period, ridge and furrow cultivation practices provided a form of surface drainage and this characteristic topography survives in many areas today.

During the 16th–19th century, the open land was enclosed forming much of the present field patterns and ditch networks, and by the end of the 19th century some science was being introduced as evidenced by Joseph Elkington's spring line interception technique.

The 19th century saw the development of clay pipes, developing from the house roof tile towards the circular pipe of present times. The mid 1800's were a 'golden age' for field drainage as the large estates recognised the long term benefits to their land that land drainage could give. A survey carried out by J Bailey Denton (1883) recorded that three million acres were drained in the period 1850–1880, but a recent review of evidence available from that period suggests that it could have been considerably more.

The impetus of the 'golden age' was not maintained, and the intense competition from imported grain from North America and a series of crop failures in the UK gave rise to a period of depression. The early 1930's saw major legislation and improvements in arterial drainage works, but it was the second world war period which saw the major redevelopment of field drainage.

From that time there has been very significant improvement in design, materials and installation techniques. At present, this country leads Europe in the field drainage league, draining approximately 100 000 ha/annum.

Drainage problems

Geographical features

The basic factor which determines the topography of England and Wales is the character of the underlying geology and the progression from the old hard rocks in the north and west to the more recent deposits in the south and east.

Broadly, the topography can be divided into three main types of terrain.

Fen or marsh – the areas of flat low-lying fen and marshland of the south and east, much of it at or below sea level.

Upland – the extensive undulating landscape characterised by the midland uplands.

Hill-land – the mountain and high hill land areas of the north and west rising to over 600 metres above sea level.

See figure 1.

Climate

The climate in England and Wales is temperate, with average

→page 108

A D Bailey CEng MICE MIMunE MIWES, is head of the Field Drainage Experimental Unit, Land Drainage Service, Ministry of Agriculture, Fisheries and Food, Anstey Hall, Maris Lane, Trumpington, Cambridge CB2 2LF

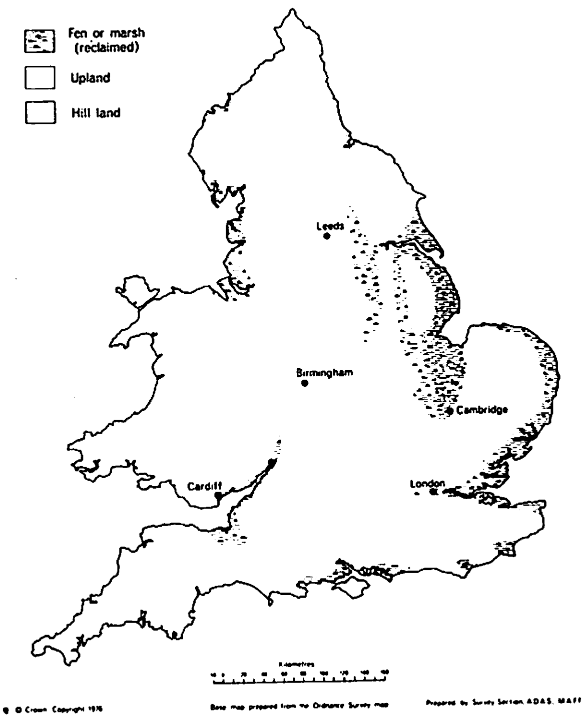
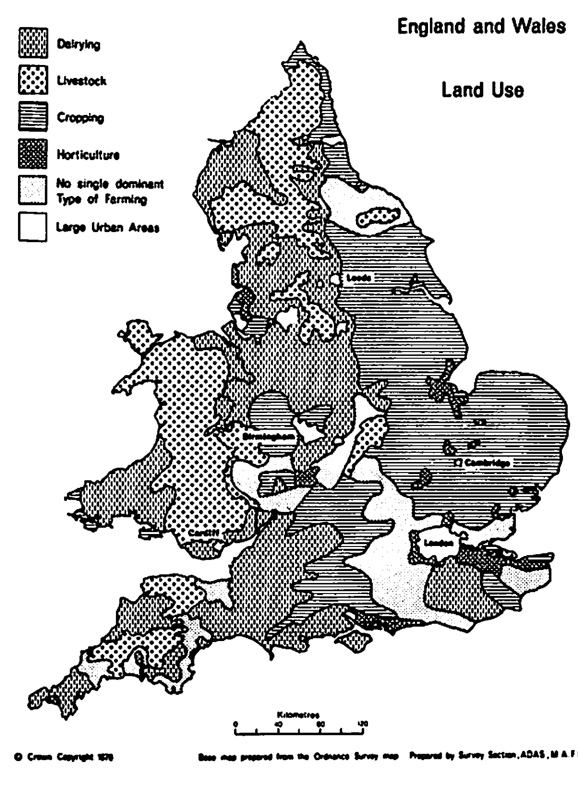


Fig 1 (above), Fig 2 (below) Maps of England and Wales showing general terrain and land use.



monthly temperatures ranging from a minimum of −1°C in winter to a maximum of 18°C in summer.

The climate is dominated by SW rain bearing winds which result in the western hill areas having high rainfalls of over 2000 mm, with intensities sometimes exceeding 100 mm/hour, while the eastern lowlands are relatively dry with annual rainfalls as low as 500 mm.

Land use

Against this background of topography, climate and associated soils, a pattern of farming has evolved. It ranges from intensive arable and horticulture on the deep fertile soils of the east, through the clay soils and mixed farming areas of the midland uplands, to the predominantly pastural farming on the shallow soils in the hill lands. See figure 2.

Predominant drainage problems

The drainage problems are related to the geological, topographical and soil features and can be identified as —

(i) Watertable problems — high groundwater conditions characteristically occur in the fen and marsh areas, with peat, sandy soils, or well structured clays.

(ii) Impermeable subsoils — there will be lack of good natural water movement below 200 mm — it is likely to be waterlogged for substantial period of the winter and show extensive signs of gleying. This problem is characteristic of the uplands.

(iii) Springs — there will be obvious signs of water breaking out, sometimes under artesian pressure. This is a typical hill land problem.

Table 1 indicates the relative percentage of drainage problems in England and Wales.

Table 1

Watertable	31%
Impermeable subsoil	60%
Springs	9%

Characteristic terrain

The geographical features and extent of drainage need are related and summrised in table 2.

Drainage need

MAFF survey

In 1969 a five per cent sample survey was carried out by the Ministry of Agriculture to determine the drainage status of agricultural land in England and Wales.

The survey involved classification of agricultural land into one of five categories. The work was carried out by the Ministry's Land Drainage Service advisers, based on geological formation and field assessment.

The five categories were —

(i) GRANT — This comprised land drained with the assistance of government aid since 1939 and is a factual record.

(ii) NATURAL — This describes naturally free draining soils, eg soils lying on chalks and well fissured limestones.

(iii) OLD — Land given this classification is known to need artificial drainage for good farming and is still being effectively drained by systems made before 1939.

(iv) IMPROVE — This covers land which relies on artificial drainage but where the drainage condition is at present substandard.

(v) OUT — This covers land that is poorly drained but is unlikely to be economically drainable because of soil conditions or lack of agricultural potential.

Table 3 — Drainage need 1968/69

Land classification	*1968/69 Estimated area in million — ha*
Grant	0.69
Natural	4.26
Old	2.17
Improve	2.88
Out	1.05
Total	11.05

Thus from the 1969 survey a drainage need was established in England and Wales on 2.88 m hectares.

A recent review of these figures has produced a 1976 drainage assessment of the following order.

Table 4 — Drainage need 1976

Land classification	*1976 — Estimated area in million — ha*
Grant	1.40
Natural	4.26
Old	1.74
Improve	2.60
Out	1.05
Total	11.05

Thus a 1976 assessment showed a drainage need of 2.60 m hectares.

Rate of drainage:

The average rate of drainage in England and Wales, over the last three years, approximates 100 000 ha/annum.

Figure 3 shows the rate of progress over the last 35 years.

Drainage benefits

The major benefits due to field drainage may be summarised as:

Yield

The yield position following drainage can vary dramatically, depending on whether the work was carried out in a reclamation situation where benefits will be high, to the situation where the benefits are marginal and drainage has been carried out as an 'insurance' against infrequent climatic stress.

Winter wheat

Most recent work in this country has been on evaluating winter wheat yields on drained clay land sites. Experiments at MAFF's

Table 2 Characteristic terrain types

Details of geographical features of terrain types and extent of drainage need.

Situation	Soils	Topography	Rainfall (mm)	Farm Size (ha)	Field Size (ha)	Cropping	Drainage Problem	Area (ha) Total	Area (ha) Requiring Drainage
Fen or Marsh	Deep fertile soils Fine sands, silts and clays. Locally extensive areas of peat.	Generally flat and low lying at 0–8m above sea level. The 'Fens' in eastern England consist of approx 100,000 ha at or below high tide levels.	500 to 600	4 to 400	2 to 8	Mainly intensive arable with roots regularly in the rotation. Locally intensive vegetable and market garden.	Water Table	800,000	400,000
Upland	Mainly clays	Generally undulating with altitudes between 8m and 180m above sea level. Locally broad flat river valleys.	600 to 900	20 to 80	2 to 6	Generally mixed farming with some permanent pasture. Locally some fruit and market garden production.	Impermeable Subsoil	6,800,000	1,600,000
Hill land	Sandy and silty clays with extensive areas of peat locally. Soils often shallow and stoney	Undulating, locally very steep. Narrow steep sided valleys with altitudes from 180m to 600m+ above sea level.	1,000 to 2,400	10 to 40	1 to 4 often including extensive areas of unfenced mountain land	Mainly pasture with locally arable and catch fodder crops.	Impermeable Subsoil/Springs	2,600,000	600,000
								10,200,000	2,600,000

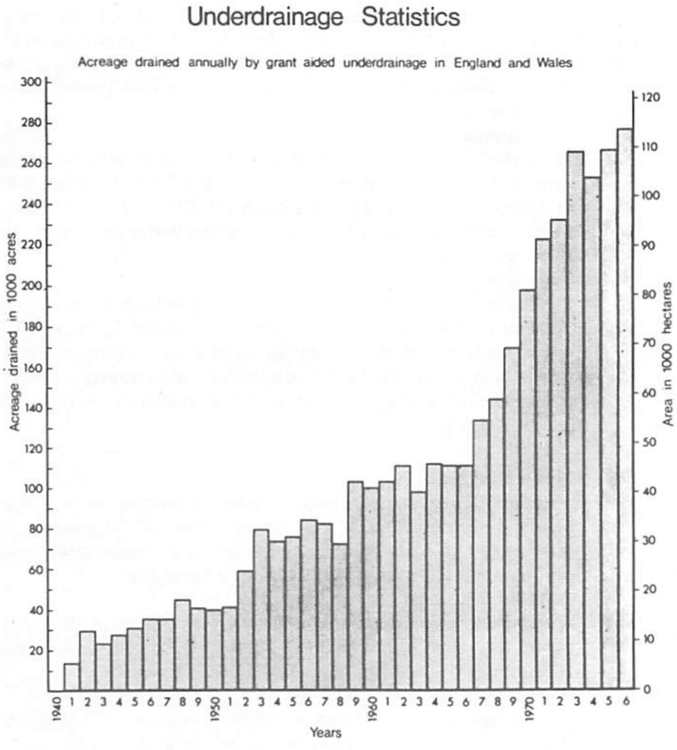


Fig 3 Underdrainage statistics

Drayton Experimental Husbandry Farm, Stratford-on-Avon, have shown an increased yield 1 tonne/ha of winter wheat on the drained plots as against the undrained control, Armstrong (1977).

Root crops

Nicholson (1958) showed that sugar beet yielded from 1.25 tonnes/ha with a watertable at 25 cm (poor drainage) to 36.25 tonnes/ha with a watertable at 80 cm (well drained).

Grass

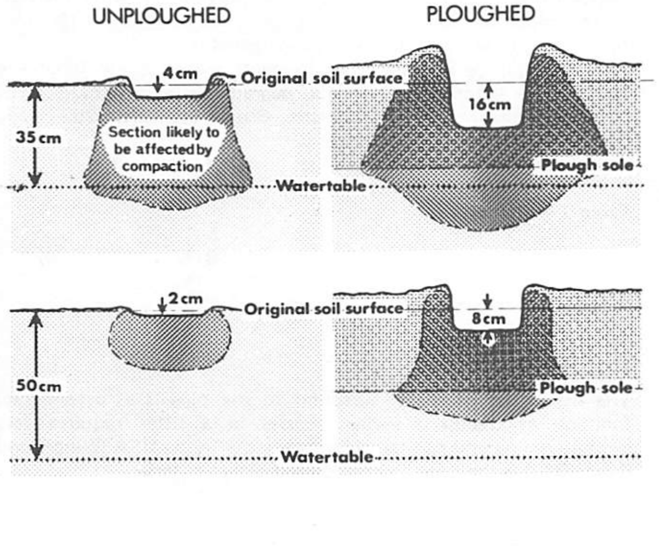
The work of Nicholson referred to above also showed that ryegrass yielded from 20 tonnes/ha to 50 tonnes/ha over a range of watertable depths from 25 cm (poor drainage) to 80 cm (well drained).

Trafford (1971) reported on yields in terms of liveweight gains of bullocks on a site at Langabeare, Devon. The results are summarised in table 5.

Table 5 – Results from Langabeare (1962–4)

Treatment	*Liveweight gain kg/ha*	*Yield % of control*
Undrained	244	100
Undrained but fertilised	306	121
Drained and fertilised	441	180
Drained, reseeded and fertilised	422	173

Fig 4 Typical wheel sinkage and compaction sections



Trafficability: Arable

Recent results from a national investigation of soil water regimes throughout the country on drained and undrained, has shown that drainage can provide up to an extra 25 work days in the autumn and 27 days in the spring, Armstrong (1977). The management options that these extra available days provide is a very real benefit at critical times in the farming calendar.

The effect of watertable on surface and subsoil have been examined. Figure 4 illustrates some results of work by Thorburn (1974) on a Cambridge clay soil. It was found that to minimise compaction a drainage system was required to maintain the watertable below 50 cm depth, and that the lowering of the watertable near the surface by 10 cm, was as effective in reducing soil compaction beneath a tractor wheel as 670 kg load reduction.

: Grassland

The poaching effect of the animal hoof can have a material effect on both the quality and the yield of grass.

In some situations the relative level of the watertable can affect the bearing strength of the surface soil by its influence on the moisture content.

Figure 5 shows the relationship of watertable/bearing strength as investigated on a boulder clay site in Lancashire by Rycroft et al (1974). From site observations it was concluded that a watertable control at 50 cm would be required to prevent poaching.

The effect of raising the bearing capacity of the soil will be the maintenance of soil structure and the extension of the grazing season earlier in the spring and later in the autumn.

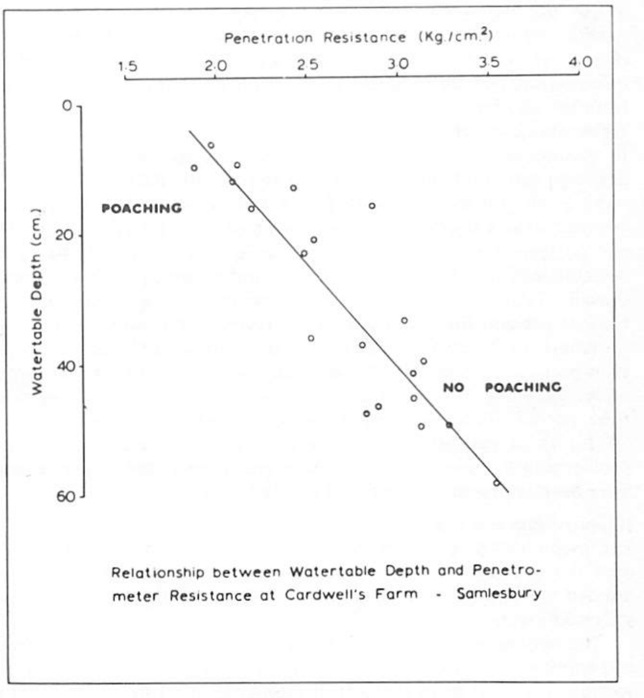


Fig 5 The relationship between water table levels and the poaching of grassland (Rycroft 1974).

Drainage costs

The major factors influencing drainage costs are the pipe spacings, the use of secondary drainage treatments, moling or subsoiling, and therefore artificial trench backfill (PF). Typical costs are shown in table 6 showing national figures and the range from Wales to eastern England.

Table 6 – Costs £/ha (1977 data)

Spacing (m)	*/treatment*	*National*	*Wales*	*Eastern Region*
8–12	Pipes only	381	389	362
18–22	Pipes only	220	268	220
36–44	Pipes only	133	–	130
8–12	Pipes + mole + PF	223	–	210
18–22	Pipes + mole + PF	361	473	374
36–44	Pipes + mole + PF	266	310	264

The national average scheme size is 7 ha, at a cost of £2,400.

Table 7 — National average costs — pence/m (based on 1975/76 data)

Specification	*Backacter*	*Continuous trencher*	*Trenchless (winched)*	*Trenchless (crawler)*
	Machine type			
75 mm clay pipe	61	39	38	36
75 mm clay pipe + PF	74	68	60	54
60/70 mm plastics	63	41	39	37
60/70 mm plastics + PF	76	70	62	56

The backacters reflect the higher unit costs of the hill land situations. The only significant differences between continuous trenchers and trenchless machine costs is where PF is used and the narrower trench of the trenchless techniques requires less gravel.

Design

Spring lines

Problems associated with spring lines require considerable site investigation and judicious location of the drain. The important points are —

(i) The drain must be as deep as possible, to effect adequate draw-down of the watertable.

(ii) The drain must be as efficient as possible to avoid water overshooting.

In straightforward situations with a relatively small total drain length, the design of an interception system may be possible without detailed knowledge of the hydraulic conductivity of the soil (ie the rate of water movement in metres/day). In complex situations, such information will be required to determine the magnitude of flow from the aquifer.

Watertable control:

In groundwater situations with a rising regional watertable, several drainage design models are available to solve the pipe depth/spacing requirement for a given level of watertable control. One solution is referred to as a steady state model, which assumes that precipitation and outflow are balanced. A condition such as this is only likely to be achieved where low intensity, long duration precipitation patterns prevail. Typical models used in European drainage are those of Hooghoudt and Ernst and as recently reviewed by van Beers (1976).

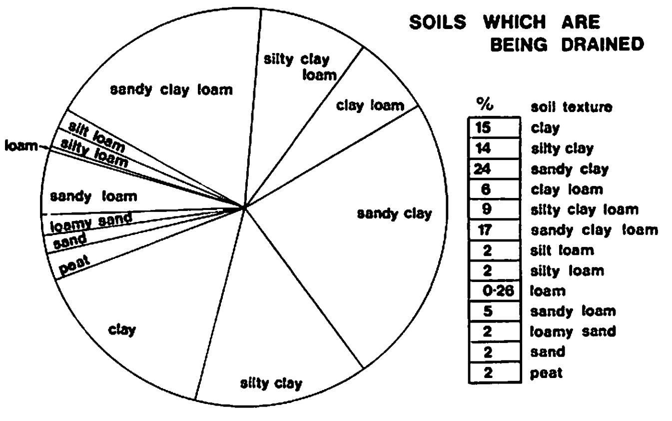
Where high intensity rainfall occurs and watertables fluctuate, then non steady state conditions apply and design criteria in terms of say reducing the watertable to a specified level within a specified time period are stated (say from surface to 50 cm depth within 24 hours of rainfall event). The solutions to these time-varying problems are more complex but several models are available and have been reviewed by van Schilfgaarde (1974).

Impermeable subsoils:

The major design problem in England and Wales is that associated with the drainage of clay soils. The textural classes of soils being drained are shown in fig 6 from which it is observed that the clay soils dominate.

The hydraulic conductivity (K) of many of these soils is very low and application of the drainage design models results in pipe spacings so close (1—2 m) as to make it uneconomic in terms of permanent pipes.

Fig 6 Pie chart showing the breakdown of subsoil textures for land currently being drained in England and Wales.



With soils of K value between 0.05 and 0.15 m/day, the only economic solution in terms of subsoil drainage is by the provision of mole channels at spacing of 1m—3m to act as 'cheap' drains, or by modifying the subsoil by shattering the soil and so increase the hydraulic conductivity.

Mole drains

Mole drains are formed by drawing a 'bullet' attached to a vertical blade through the soil, with a 10 cm diameter ball attached as an 'expander', at a depth of 60 cm. The soil needs to be plastic so as to form a channel for water movement to the drain.

Subsoiling

Subsoiling must shatter the subsoil to the extent of improving permeability and the 'K' value. Recent work by Spoor (1976) has identified that work must be kept above a critical depth if the failure is to be brittle rather than plastic. Under conditions in this country this critical depth is unlikely to exceed 40 cm.

Layout

Springlines

Springline problems will require random layouts, on line and depth dictated by the specific problem. As discussed, a satisfactory solution requires considerable investigation and skill in siting the drain for maximum interception.

Watertable control

A typical drain layout for groundwater control in the Fens would be parallel 55/75 mm dia pipes, 20 metres spacing 1.20 metres deep, with individual outfalls to ditches.

Heavy clay land

On a sloping clay land site, suitable for moling, the laterals, 70/75 or 100 mm diameter, would be placed across the slope to intercept downslope movement of water, at a depth of 900 mm, with permeable fill to connect mole channels drawn with the slope at 2—3 metre centres. The spacing of the pipe laterals is dependent upon the stability of the soil to retain a mole channel; eg very highly stable soils — spacing 80 m, stable soils — 20 m.

Pipe diameter

The pipe size is detemined by the design rainfall, pipe material, the pipe gradient and the area of land draining to the pipe. Design tables have been produced by MAFF to cover all available pipes in this country.

Materials

All work carried out in England and Wales which qualifies for Government grant-aid is required to conform with MAFF Technical Note on Workmanship and Materials.

The basic materials in field drainage are:

Pipes

The major materials for subsoil drainage pipes are clay and plastics.

Clay pipes — As discussed earlier, clay pipes have been used traditionally since the mid-19th century. The 75 mm diameter clay pipe is far the most common pipe used in present day drainage. Clay pipes in the 75 mm — 100 mm diameter range in agricultural land, adequately meet the loading imposed by agricultural type vehicles — most damage is caused by stresses induced in handling and transport. Clay land drainage pipes are required to conform to BS 1196.

Plastics pipes These pipes ara available in polyethylene (PE), polyvinylchloride (PVC) and unplasticised polyvinylchloride (uPVC).

The pipes are available in a range from 50 mm — 100 mm diameter, in both rigid and coiled, corrugated form.

The major performance requirements are adequate flexibility resistance to deformation, impact, degradation when stored in the open and damage by soil and water. British Standard 4962 covers plastics subsoil drains.

Relative use of clay/plastics pipes is shown in table 8.

Table 8 — Pipe usage

Clayware	81%
PVC rigid	1%
PVC corrugated	17%
PE	1%

Filters

The major use of gravel surround to the pipe is as a connector function as discussed earlier. Gravel as a filter requires very careful grading and can be expensive, work in the USA (Winger and Ryan 1970) is the generally recognised design criteria.

Synthetic materials are now available commercially in the form of a wrap for plastics pipes. Typical examples are "Cocos" and "Filtan".

Siltation problems in the UK are not great, less than one per cent of pipes used use filter wraps and this reflects the scale of need. Vulnerable soils are those which are not well graded and where 80% or more of the particle size distribution lies in the very fine sand range.

Permeable trench backfill (PF)

As mentioned previously, the need for PF on many schemes makes it an important factor; it can account for 60% of the total cost of a drainage scheme.

PF is placed over the pipe to within 40 cm of the surface to ensure a good connection with the mole channel or subsoiled zone. For practical reasons the full trench width is filled but experimental work at the FDEU (Dennis 1977) suggests that a width of 100 mm would be adequate.

The materials used are shown in table 9.

Table 9

Washed gravel	92%
Reject gravel	2%
Furnace clinker	5%
Synthetic gravels	1%

Installation

Practically all drainage work in England and Wales is now installed by machine. The current situation of machine performance has been reviewed by Bailey and Trafford (1977). Most work is installed by continuous trenchers as shown in table 10.

Table 10

Backacter	9%
Continuous trencher	83%
Trenchless (winched)	6%
Trenchless (crawler)	2%

Backacter

An extremely versatile machine, tracked or wheeled, and now mostly hydraulic controlled. It is not exclusive to field drainage works and has universal use outside this activity.

It is used on hill land drainage projects, small schemes, rocky ground conditions, spring interception schemes, and in support to continuous trenchers and trenchless machines.

Continuous trenchers

They cover a very wide range — tracked, four wheel drive, rotaped and towed. Digging conditions include continuous chain, centre wheel drive or rim drive. There are variations of mechanical and hydrostatic drive, geared or infinitely variable speeds, related or unrelated to rate of forward travel. There is considerable variation on digging depth maximum.

These machines carry out by far the largest amount of work in this country, the wide range providing considerable versatility. The larger machines work well on the big fenland schemes in the east of England.

Trenchless

The technology associated with trenchless drain laying is developing steadily. The versatility is found in the combined range of winched and tracked machines.

Table 11 — Drainage machinery performance — smaller/larger machines

Machine type	*Power (kW)*	*Maximum digging depth (m)*	*Trench width (mm)*	*Working speed (km/hr)*
Backacter	36/62	3.5/4.5	205/610	0.2
Continuous trenchers				
a. Chain digger	56/165	1.5/3.5	140/450	0.5/4.6
b. Wheel digger	50	1.8	125/600	0.2/1.0
Trenchless				
a. Winched	22/78	1.2/1.7	120/230	2.0
b. Crawler	100/200	1.5/2.1	120/200	2.0/5.5

Their utilisation in this country is not great but is increasing; manufacturers are providing for the machines to handle both clay and plastics pipe, but their potential seems to be very much related to coiled plastics pipe.

Typical specification and performance of machines are summarised in table 11.

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Tecnical help to exporters

THE BSI publication *Technical Export News* reported in its September issue on the steps which have already been taken by THE to provide technical information for exporters of agricultural equipment.

The service will cover the following types of agricultural equipment: Tractors (wheeled and track), cultivation equipment (ploughs, primary cultivation and seed-bed preparation), sowing and planting equipment, combine harvesters, forage handling equipment, bale handling equipment, root and vegetable harvesting equipment, and second-hand equipment.

A pilot exercise, conducted in the Federal Republic of Germany, has yielded information on the detailed requirements which British manufacturers must meet in exporting their equipment to Germany.

It is hoped that the German manuals will be available at the end of September. The costing for these documents is: £500 for the four manuals and £200 for up-dating for one year, from 1 October.

A further one-day conference, more detailed than its predecessor held last March, will take place at the Wembley Conference Centre on 31 January 1979. Papers will cover the export of mobile agricultural machinery to Germany (FR), France, Sweden and the EEC. Details may be obtained from Promotion Services Department, Technical Help to Exporters, BSI, Maylands Avenue, Hemel Hempstead, Hertfordshire HP2 4SQ.

Erratum

In Vol 33 No 2, Summer 1978, page 56, A J Casebow of Scott Wilson Kirkpatrick and Partners was wrongly quoted. His statement was that "93% of farms in Orissa State, India, are less than five hectares".

AAG one-day symposium

THE Agricultural Aviation Group of the Royal Aeronautical Society is holding a one day symposium at the Society's headquarters on Wednesday 14 February 1979. The morning session is to be devoted to a review of the role of helicopters in agricultural aviation, and the afternoon session will consist of papers on the safety and environmental aspect of aerial spraying.

Full details can be obtained from Miss J Macbean, Symposium Secretary, Royal Aeronautical Society, 4 Hamilton Place, London W1V 9BQ (tel 01-499 3515).

A report on the second international green crops drying congress (DRI-CROPS 78)

G Shepperson

Aims of the congress

AS the second in a series of meetings, started at Oxford with Dri-Crops 73, the programme was planned to outline the development of methods to produce high quality feeds from green forage crops, and to emphasise the need for economy in the use of energy.

An opening paper, "Forage Crops in Perspective" given by Dr C M Williams, Head of the Department of Animal and Poultry Science at the University of Saskatchewan, set the theme for the Congress.

Problems to be studied were the physiology of drying, the need to reduce energy costs and losses of feed value during conservation, and the reduction of the total cost of processing and storage. Products to be considered were the whole plant, for ruminant feeding, pellets for all stock and leaf protein concentrates (LPC) as a high quality protein supplement, capable of replacing soya. Livestock production in developing countries was considered to be the key to future production, where it could provide an outlet for dried grass and lucerne from developed countries.

Green crop drying, which maximises the recovery and use of forage nutrients, is most suited to developed countries, where it can improve land use. Although green crop drying makes efficient use of resources complementary to agriculture, it also uses fossilised fuel, which is rising in cost; potential shortage may even lead to restrictions on its use for crop drying. Hence, systems must be developed which make the maximum use of waste heat.

Congress programme

The technical sessions dealt with the following subjects:

a. Green crop fractionation
b. Agronomy
c. Harvesting
d. Drying and processing
e. Livestock feeding
f. Marketing and economics

All papers presented, together with the main discussion points will be published as a Proceedings, which was expected to be ready in October 1978. Meanwhile, a copy of the full visit report, paper titles, or of paper summaries can be obtained from the present author. Although much of the European data had previously been reported elsewhere, papers prepared especially for the Congress updated past research, highlighted some developments, and created an awareness of work on a world-wide scale.

Green crop fractionation

In the Philippines six potentially high yielding crops, with 16% to 30% protein in the dry matter have been examined in plot trials to determine their value for protein extraction; Tamling (Gymnopetalum cochinchinense) appeared to be most promising. Similar studies of 70 species and varieties of legume and grasses have been made in Italy, where forage crops supply 56% of all feed for livestock. Of special interest is their development of the Poly – Protein process for LPC, in which proteins are precipitated by adding polyelectrolytes to expressed juice at room temperature; a procedure involving pigment extraction and centrifuging has also been developed.

The interest at Guelph, Canada was in feeding heat coagulated juice to calves as a milk replacer; it was readily drunk by young calves and there were few health problems. It was concluded, however, that LPC was not equivalent to soya bean meal, and the process was considered unsuitable for on-farm use because it was difficult to adapt on a small scale. Handling the bulk involved was more difficult than expected.

Subsequent speakers did not accept such outright condemnation of juice extraction as an on-farm process, and in particular work continues at Wisconsin to develop equipment which can be scaled up from the present throughput of 5.4 t/h of green forage.

G Shepperson is from the Forage Conservation Department, NIAE Silsoe.

At USDA, Berkeley, where much of the large scale work on the production of LPC (Pro-Xan) has been initiated, research and development continues to produce feeds which are suitable both for animals and man. Advances have been the development of a vertical shaft hammer mill to rupture 10–15 t/h of fresh crop. Grinding of the fresh crop, compared with chopping alone has increased juice yield by 21.5% and LPC yield by over 60%; yield has also been increased by adding back deproteinised juice to the grinder and by double pressing.

The practical aspects of crop fractionation and the reduction of energy costs, using equipment which also eliminates atmospheric pollution, were outlined by representatives of France Luzerne and Eva-Dry. In a plant producing 18 000 t pellets annually, there has been a 40% increase in evaporative capacity and a 30% saving in total energy requirement.

The use of the products of fractionation for feeding dairy cows and pigs was put into perspective by Connell from NIRD, who drew attention to the need to consider carefully the use of the primary product, pressed forage, and reminded delegates that "The dairy cow is a good converter of green forage to white protein"! A maximum of 15% of protein should be removed as LPC, and the ruminant is likely to consume 90% of lucerne passed through the fractionation process. The conclusion from research has been that correctly produced LPC can be confidently fed to pigs and poultry, but feeding juice to pigs in farm trials has been disappointing, and at present there is no satisfactory explanation of these results.

The theoretical possibilities of developing economic LPC production in the UK, and the practicality of using heat recycling equipment on grass driers were presented in a study made jointly by Reading University, GRI and NIRD. Overall conclusions to be drawn from this and other papers in the session were:

i) A high grade protein can be produced and fed successfully to monogastric animals.
ii) The pressed forage is a suitable ruminant feed, but the class of animals to which it can be fed depends on the extraction rate of protein.
iii) It will be technically feasible to produce a colourless taint free soluble protein suitable for feeding to humans.
iv) Large scale commercial fractionation has no future unless a high price is paid for pigmenting products in the LPC, eg Xanthophyll, and substantial installation grants are available.
v) On-farm scale operation requires the development of simple low cost equipment, but even if this can be made and marketed at an economic price, handling and management problems may make the process impracticable.
vi) In the long term crop fractionation may be justified on the grounds of fuel costs and economy of use, coupled with the requirement to minimise atmospheric pollution.

Drying and processing

Five papers were presented about ways to reduce the loss of energy from driers by recycling waste heat. The aim is to recover latent heat from the exhausted water vapour and to use it to pre-dry the crop, or to heat it before pressing, and then remove water from expressed juice, often at reduced pressure. Pre-heating the crop precipitates protein so that when it is screw-pressed only a small amount of dry matter and protein is removed in the juice.

Emphasis was placed, in a paper from the Biotechnical Institute at Kolding, Denmark, on the need to heat crop thoroughly before pressing out juice. Pilot trials have confirmed that when using vacuum evaporators 70% of the energy in the exhaust gas can be used. It has been calculated that with complete heat recovery equipment 40–50% energy can be saved over a season when drying lucerne or grass with an average dry matter content of 22%.

Details of commercial developments and installations were presented in papers from Atlas, Van den Broek, Combi and Promill, and the main features have been reported in Agricultural Engineer (Vol 33 No 1).

As the papers on wet fractionation and the production of LPC were presented separately from those dealing with waste heat recovery, the impact of the possible relationship between the two processes was not fully explored. However, the joint contribution from France Luzerne and Alfa-Laval, about industrial production of leaf protein and energy economy helped delegates to appreciate the way in which reduction in specific fuel requirement and the separation of excess protein from forage feeds for ruminants could complement each other.

For some parts of the world elimination of the use of fossilised fuels for drying is a practical proposition. In New Zealand plants with an output of 1 t/h of dried alfalfa have been designed to work with geothermal steam. In 1977, about 1700 t of dried crop were made; optimum size of units for the future appears to be an output of 1.4 t/h, and total output from the scheme may reach 20 000 t annually.

Other papers in this session dealt with drier operation, control and processing. Advantages and disadvantages of triple and single pass driers and of positive versus negative pneumatic conveying systems were outlined by a leading American manufacturer (MEC). Conclusions were that the single pass positive system in which the fan is sited between the drier and cyclone is generally the most economical design for initial and operating costs, but the negative system, which requires a rotary valve on the cyclone provides the greatest product tolerance. Triple pass negative systems combine good operational characteristics with high efficiency, and when fitted with exhaust gas recycling offer the best design for overall efficiency and pollution control.

The improvement of dehydrator management by more accurate control of final moisture content was discussed in another paper, which described equipment which measures the dielectric constant of the dried crop; it can monitor 8 channels and may be used to control such factors as drier temperature and input rate of total crop and water. Work at Uppsala on adaptive optimal control of high temperature driers assumes that conventional controllers may suit one set of circumstances but perform very badly when parameters such as crop type, structure and moisture content change. Adaptive control, which continuously modifies a mathematical model of the plant is proposed, and a regulator, implemented on a microcomputer, is being used in 1978.

Harvesting

The emphasis of papers in this section was on field wilting, still the cheapest, even if unreliable method of reducing drying loads and fuel costs.

Attention was drawn to the importance of the swath formed by mower conditioners, in relation to rate of moisture loss, loss of dry matter and the requirements of harvesters. Reference was made to conditioning equipment developed at NIAE, Silsoe, roller crushers and full width conditioning.

An interesting method to increase field drying has been developed at Purdue, where the aim is to cut, package and store lucerne hay in one day. Using a 1 ft wide model, alfalfa stalks are mechanically sheared and flattened with two corrugated or saw toothed pattern rollers, rotating at different speeds.

A paper from USSR stated that the experimental use of anhydrous ammonia to hasten wilting of standing crops appears to be economical but no machine is available to develop the method on a practical scale. The more reliable method of mechanical dewatering, developed at Wisconsin was described in some detail and a model has been developed to predict drying rate, drier capacity and fuel savings; predicted and observed values are very close. Trials to determine the loss in nutritive value caused by field wilting, especially in California and Kansas where it may be possible to wilt from over 80% to as little as 30% mc in 6 h, have shown that 60% of carotene and 4% protein can be lost in 10 h.

Livestock feeding

Papers in this section dealt with the use of dried products in rations for all classes of stock and especially for ruminants. The general conclusion to be drawn was that dried grass and lucerne has many advantages as a feed which should be exploited when attempting to sell in competition with protein and cereal concentrates. In fact, the large deficit in animal feed production in many areas could be offset by drying high quality forages, especially if more use can be made of geothermal heat and solar energy.

One paper of particular interest described work by USDA and Pennsylvania State University into the use of infrared reflectance spectroscopy to predict forage quality. A new instrument, used with a small monochromator and an LSI 11 microprocessor has been developed as part of a research project; it can be used to predict differences between heat-damaged and undamaged protein, as well as levels of nitrogen, fibre and some minerals.

Another paper from USDA Beltsville, brought together the importance of good control of the drier and the potential benefits of heat processing on the utilisation of nitrogen. Heat treatment can reduce the degradation of protein to non-protein nitrogen in the rumen, but heat damage decreases protein digestibility and its ultimate utilisation. The correct balance of temperature, residence time and final moisture content is important and although not fully evaluated, it seems that the final dry matter should be about 90%, and that a temperature over 150°C should be applied only when the dry matter is less than that.

Marketing and economics

This session dealt mainly with the problem of selling the crop. As a marketing co-operative France Luzerne is aware of the need for quality control and the provision of a guaranteed standardised product for feeding, but considers that the development of new techniques, equipment and products must be coupled with at least a 35% saving in energy, as well as protein extraction. The American Dehydrators Association, with 1.3 M tons of alfalfa to sell annually, are also conscious of the need for uniformity of nutrient and physical quality. Most of their crop, containing 17% crude protein, is sold to feed compounders and although there have been large shipments to Europe since 1975, this is not regarded as a long term market.

On a world basis there was 4.7 Mt of dehydrated products in 1977, to which USA contributed 30%, France 16%, Hungary 11%, Canada 6% and Denmark 5%. Total figures are incomplete because no data are available for USSR, China or Argentina. Output is likely to continue to increase in France and decrease in USA and Denmark.

A final paper dealt with the place of the Canadian dehydration industry. Thirty plants are now in operation of which 14 are in Alberta and 11 in Saskatchewan. Total production of dried and sun cured lucerne was 310 800 t in 1977–78, of which 194 000 t was exported, including 140 000 t to Japan. But freight costs have almost doubled over the past 8 years, and as the average sale price of $195/t is about $10/t less than the production costs, the Canadian industry is facing imminent downfall unless there is a change in the pricing structure.

In summing up this session the Chairman (Edgar Phillips of BAGCD) put forward the suggestion that consideration should be given by the various countries involved to the formation of a Committee to promote the sale of dehydrated legumes and grass. Ample evidence had been presented during the course of the week about the potential of the industry and the value of the product as an animal feed. Continuing survival seems to be a question of adapting to changing circumstances, reducing production costs by using less fuel per ton and increasing output, and exploiting the special value of dried grass as a feed, in competition with other products.

Conclusions

i) The cost of drying and amount of fossil fuel used must be reduced by field wilting or the installation of heat recovery systems.
ii) Improved varieties of lucerne and better sward management are needed to give higher yields of protein.
iii) Heat treatment of protein can be beneficial for ruminant feed but heat damage causes a loss in protein digestibility.
iv) Economic considerations centre mainly on capital cost, the cost and future scarcity of oil and the need for a global marketing policy of dried grass and lucerne.

A third meeting is planned for autumn 1982 in France, when the aim will be to continue the basic idea behind the first Dri-crops meeting of bringing producers, manufacturers, and research workers together to discuss problems of mutual interest. Special attention will be paid to marketing, practical management, production problems, and the needs of dehydrators.

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In-house injection moulding

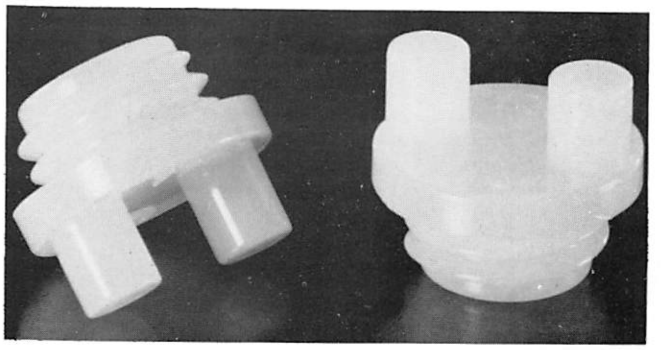
A WELL known Midlands company, manufacturing light agricultural and horticultural machinery, reports considerable benefits following the introduction of a 3 oz injection moulding machine* into its works. The injection moulder is used for the production in nylon of small precision components previously manufactured by machining, or obtained from outside suppliers.

An example of the sort of work now produced by injection moulding is a small gear wheel forming part of a horse and cattle clipper. This component was formerly machined from a Tufnol blank, and required a centre hole to receive the pressed-in knurled end of a driving spindle. The wheel was then turned on a centre lathe and faced, the gear teeth finally being cut on a hobbing machine. The tooth form of the gear wheel was exceptionally fine, and it was necessary to cut the teeth with the hobbing machine running at minimum speed. If accidental damage occurred during the process, both gear wheel and spindle had to be scrapped. Production of each gear wheel took an average of 20 minutes.

A 3 oz injection moulding machine has reduced production time per gear wheel to around ¾ minute. The wheel is now moulded in nylon, directly on to a threaded metal spindle, which, in the event of scrapping of the gear wheel due to a fault, can be unscrewed and re-used. Other components can also be produced on the moulding machine, and the firm concerned now produces its own oil filler plugs for gear cases, components forming the throttle control for walking tractors and spacers used with printed circuit boards for electrical fencer units.

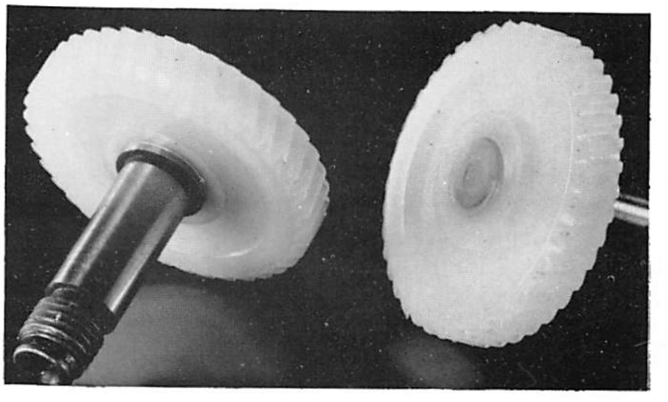
The development director of the company using the injection moulding machine states that it has worked reliably since its installation in 1972; it is inexpensive in capital and operating costs; it is compact and versatile in that small production runs can be made economically; and production can be switched to another component in minutes.

**The Manumold by Florin Ltd, 457/463 Caledonian Road, London N7 9BB. (Tel. 01-609 0011).*



Oil filler plugs moulded on the Manumold.

Nylon gear wheels moulded on the Manumold



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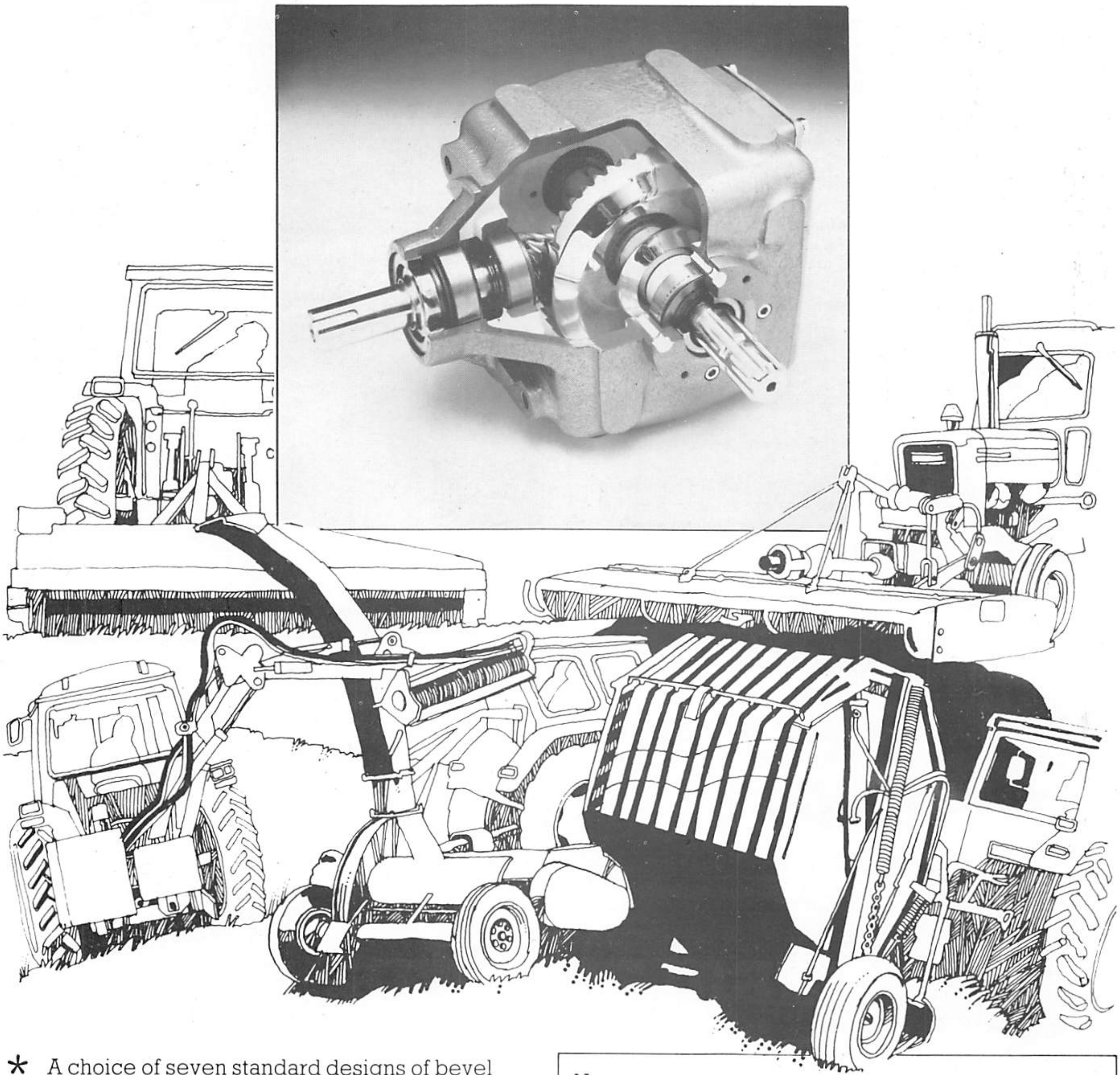

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