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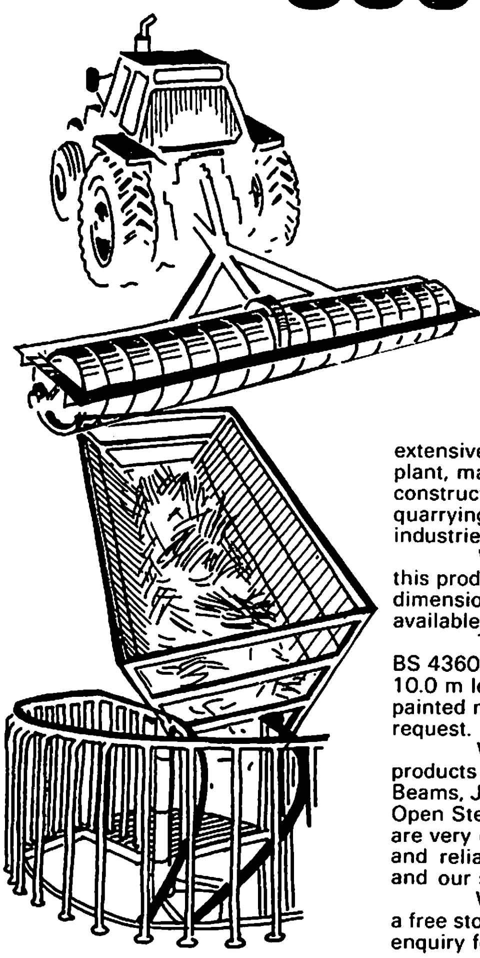

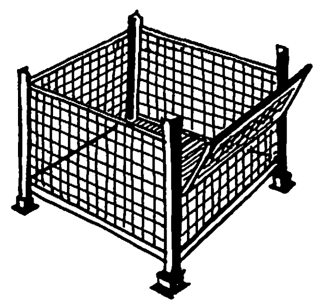

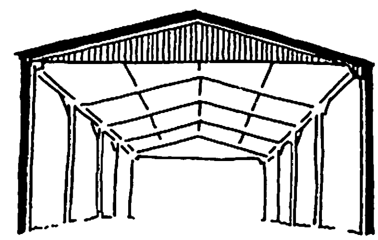

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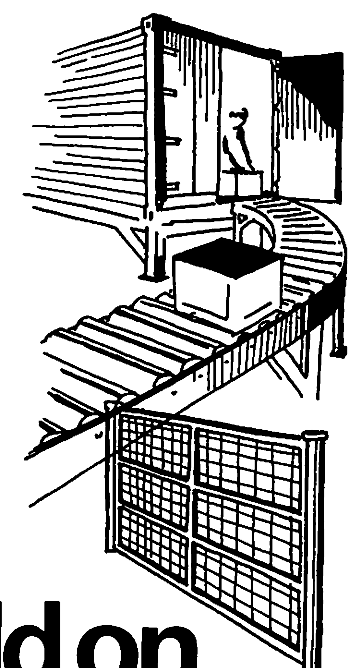

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THE
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Cover — Top: HRH Duke of Edinburgh is met at the door of NCAE by IAgrE President John Weeks. In the background about to meet the Duke are l to r Messrs E Southcombe, M Nellist and Ray Fryett
Bottom: The Duke meets Mr T Sherwen, Chairman of the Douglas Bomford Trust. Also illustrated l to r Messrs B Stenning, J Turner and K Axford

Douglas Bomford Third Memorial Lecture

Dr F E Jones, director of Unitech Ltd, is presented to HRH The Duke of Edinburgh

AN ANALYSIS OF ECONOMIC SUCCESS IN AGRICULTURAL ENGINEERING was the title of the Douglas Bomford Memorial lecture given by Dr F E Jones, Director of Unitech Ltd. and President of the Engineering Industries Association, on 17 October. Held at the National College of Agricultural Engineering, the lecture was attended by H R H The Duke of Edinburgh and over 300 members and guests of The Institution of Agricultural Engineers.

Dr Jones presented a fascinating and thought-provoking analysis of twelve agricultural engineering companies. These were Claas GmBH (Germany), Deere & Co (USA), Iseki Co (Japan),, Kubota Co (Japan), Vicon NV (Holland) and the following UK based companies: E H Bentall & Co Ltd, Bomford and Evershed Ltd, Howard Machinery Ltd, International Harvester Co of GB Ltd, Blackwood Hodge Ltd, and two other companies known as UK "A" and UK "B".

The term "added value" was defined as the difference between what a company pays for necessary raw materials, components and services, and the income from customers who purchase the wares of the company.

Two criteria of successful business, suggested by Dr Jones, were the "added value per £ of total assets" and the "added value per £ of fixed assets". These items determine the efficiency with which a company uses its assets and have a direct bearing on the wage rates which it can afford to pay.

For the two most successful of the companies under discussion, the figures were as follows:

	Added value per £ of total assets	Added value per £ of fixed assets
Deere & Co	£0.57	£2.64
Bomford & Evershed Ltd	£0.53	£1.93

The growth of companies was also discussed, being a determining factor in the stability of employment and the future wellbeing of the employees, the company and the State. Vicon and Deere claimed top places here.

The speaker emphasised that his analysis was concerned only with "good housekeeping". Clearly good products were also essential. To ensure that good housekeeping was achieved it was perhaps reasonable to suggest that one should start from a decision of the wage rates which one wished to pay. Pursuing this example, for a fictitious business, Dr Jones continued:

"From this one can easily arrive at the added value necessary to support economically this wage and in turn from this added value one can find the asset structure one needs to generate this amount of added value. Thus suppose that in our company we wish to pay an average wage/salary of £5000 per year and this is linked to social service and pension payments of £1000 per year giving total wage costs of £6000 per year. We will assume that we have decided that this should be 60% of the added value and that we must therefore plan for an added value of £10,000 per year per employee. We also have worked out that our efficiency in the use of assets comes out at £0.5 of added value for each £ of total assets. Thus we must plan for £20,000 of assets per employee. We will further assume that of this £20,000 of total assets we shall need finance for 70% of it amounting to £14,000 per job of which 50% will be financed by shareholders' funds and 50% by bank borrowing. We will also assume that in our company we will manufacture half of what we sell and buy in one half. Then for our 'good' manufacturing company we have the following figures:—

Performance of UK based Omega Agricultural Engineering Company Limited 1978/9

Employees 100 Total assets £2.0m

Total assets comprise buildings, plant and machinery at depreciated value £660,000 (33%), stocks £500,000 (25%), debtors £500,000 (25%) and cash £340,000 (17%).

Shareholders' funds £700,000 — Shareholders' funds per employee £7,000

Total assets per employee £20,000 — *Fixed assets per employee* £6,600

Performance per employee

Sales	£20,000	
Bought in goods and services	10,000	Vertical integration 50%
ADDED VALUE	10,000	

Distribution of added value per employee

	£	%
Wages and salaries	5,000	50.0
Social service and pension charges	1,000	10.0
Rent and hire	200	2.0
Interested on borrowed capital	700	7.0
Local rates	100	1.0
Corporation tax	900	9.0
Net profit (after tax)	1,200	12.0
Depreciation	900	9.0
ADDED VALUE	10,000	100.0
Added value per £ of total assets	£0.50	
Added value per £ of fixed assets	£1.50	

Total added value created by company £1,000,000.
Research and Development expenditure £50,000.

With the above characteristics the company should grow at about two per cent per year net of inflation and in these circumstances it would rank fifth in our consolidated table alongside Bentall. Good management could possibly get the added value per £ of total assets up well above the 0.5 figure we have used — the figure achieved by General Motors is £1.09 — and it will be seen that any improvement here appears as money in the item covered by net profit and corporation tax, an item much revered by all management."

The inspiration for the lecture came from David Manby, immediate Past President of the Institution to whom, with the Douglas Bomford Trustees, the chairman and officers of the South East Midlands Branch and the ever watchful Secretariat should be offered the congratulations of the Institution.

Copies of Dr Jones' full paper, together with an edited summary of the ensuing discussion, will be available from the Institution Secretary.

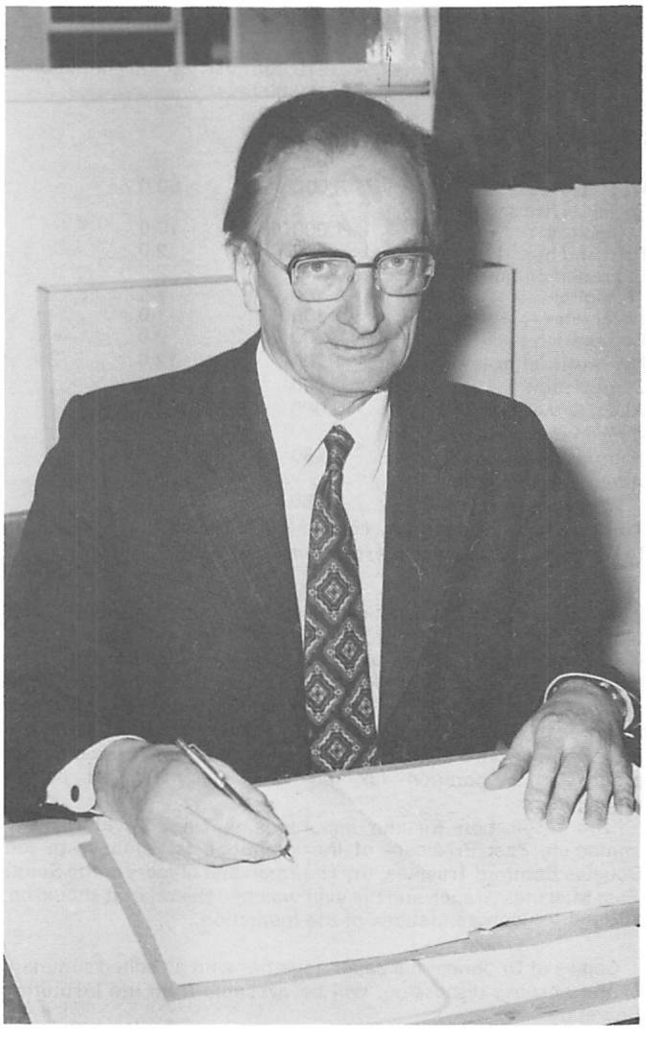
Tillage equipment design and power requirement in the 80's

R McD Graham

THE history of agricultural productivity since the second world war shows an intensification of crop production, together with closer rotations, (or no rotations), and in many cases going against long accepted principles of good husbandry. There has been a spectacular increase in the yields of many crops over the last 30 to 35 years. However, in recent years there have been cases of some of our most productive land not showing the increases which are seen on some other, perhaps not so productive, soil types. There are many influential factors here but a major one must be the way that soil is treated.

Ever since the publication of the report of the Agricultural Advisory Council on 'Soil Structure and Soil Fertility' in 1970 (the Strutt Report) these problems have been uppermost in the minds of many farmers, soil scientists, advisers and agricultural engineers. The result has been a stimulation of research into aspects of the relationships between plants and the soil in which they grow and the best way of achieving or improving this relationship. This in turn points to agricultural engineering developments and contributions which the engineer can make to a solution of these problems.

Another important and topical subject is that of fossil fuel economy and while British agriculture is only a relatively small user of these fuels it still behoves it to economise where possible, not least because fuel is becoming more and more expensive.



This then is the background against which the Institution of Agricultural Engineers decided on the title of the 1979 Autumn Conference 'Tillage Equipment Design and Power Requirement in the 80's." In this Conference too, it had the ready co-operation of the Royal Agricultural Society of England.

Such a subject falls naturally into two sections:

1. What is required.
2. How to achieve it, and the speakers into two categories, soil experts and engineers.

The theme for the Conference is ably set by David Scott in his first paper. He farms some 2000 acres in Shropshire and is continuously looking at new techniques with a view to developing them in the future in his own farming enterprises, over which he exercises a high degree of discipline. His thoughtful paper indicates the way in which he personally sees cultivations and power requirements moving in the future and he poses many questions of a fundamental nature to the soil scientist and the agricultural engineer.

Letcombe Laboratory is carrying out a great deal of research into the relationships between the plant and its soil environment. Does the ideal plant environment require a cultivated soil and if so can this requirement be measured or a seed bed specification drawn up? These aspects are covered by Dr Robert Cannell within whose department at Letcombe this research work is carried on.

Dr Bryan Davies, Regional Soil Scientist for ADAS, Cambridge, speaks of the past, present and possible future cultivation practices and considers these in relation to a number of different crops. He makes a plea for farmers to develop skills of soil examination and interpretation, a subject most sadly neglected in the past. This can assist in deciding on the soil treatment, whether just to undo compaction damage or to achieve some other objective in relation to soil condition.

The remaining three papers are concerned with engineering aspects. Dr Blight, who directs the Scottish Institute of Agricultural Engineering, where much research work has been carried out into powered cultivations, points out the vastness of the subject and that some fundamental features have not yet been firmly established, mainly owing to lack of precise knowledge of the conditions which are required. Probably the most outstanding research need is a means of relating cultivation performance to subsequent crop performance.

The question of power requirement for cultivations is dealt with by John Matthews of NIAE who has made a speciality of this subject. Again the problems of measuring what is done to the soil against the benefits derived both from shallow cultivations and deep tillage are highlighted. He goes on to summarise the savings in energy input of reduced cultivations and direct drilling compared with traditional methods. From this the most economical tractor size is promulgated together with the ground pressure which it will exert in order to minimise soil compaction.

And so to the final challenge of the Conference, made by Professor J R O'Callaghan, Pro-Vice-Chancellor of the University of Newcastle upon Tyne, 'Can the Engineering Industry meet the requirements of the Farming Industry in the Future?' What more does it need to do this? The effectiveness of the energy input when planting a crop needs to be increased so that the overall energy ratio of the systems is improved. This means that cultivation machinery must be improved both in function and in fabrication. The manufacturing industry must have the support of its customers, the farmers, and development must be a partnership between the farmer and the manufacturer with the assistance of research findings. If British manufacturers will stand behind their engineering staff in development and production, machines will be produced which the British farmer will be prepared to buy.

R McD Graham is Agricultural Adviser at Massey-Ferguson (UK) Ltd.

What will I require in the '80's – a farmer's opinion

David L U Scott

Summary

Awareness of soil structure and its interaction with the crop is of increasing importance. Improvements in traction, perhaps arising from reconsideration of existing principles and from the development of wheels and tyres, is hoped for. The comfort and convenience of the tractor driver also merit greater attention.

A testing service, complementary to that in Europe, is needed. Service of new machinery must be high quality. Longer life of wearing parts would be welcomed and a plea for more standardisation of components is made

1 How often in life good comes from a crisis. The shortage of energy in the past months has done more to alert us to a future shortage than any number of gradual price increases. In fact oil was five per cent of our costs in 1969 and even in the current year will only rise to eight per cent. However, this is not the whole story, because oil affects the end price of almost everything we use. Fertiliser and chemicals alone have now replaced wages as the second largest item of expense after power — these two amounting to almost 50% of total costs!

It can be seen therefore that the efficient and economical use of resources is a vital factor in future farm planning.

Due to increased end-prices in the past seven years — Barley was £23 in January 1972 — and a tendency for costs to follow, a great deal of "Gearing-up" has taken place, some of which has been uneconomic and must now be seriously re-assessed.

It is very easy to invest but are we asking the right questions before we do so or are we persuaded by enthusiastic employees looking over the hedges. I find it vital to accept the discipline of capital budgeting — it

Curbs whims and stops impulse buying
Makes for better planning
Most important — allows time to consider choice

It is exceedingly difficult to go back and re-question previous decisions, but this we must do if we are to maintain margins and remain competitive, and no doubt replacement costs will add their own financial pressures to the argument.

One of the important factors to consider is the future scale of farm units. I do not believe units will expand as rapidly as in the past, as capital taxation is bound to cause break-ups and the high capital cost of land will limit individual growth.

Also, since reasonable profit margins have been generated during the past few years, much has gone into farm expansion and inevitably, as margins tighten, so will the availability of cash to expand. The banks, who have taken a leading part in the encouragement of expansion, will be less willing partners in the future, if the profits are not forthcoming.

We have also in the 70's seen the serious development of company farming and involvement by the institutions. I may be naive but I believe that agriculture does not lend itself to company organisation nor do I see it having any benefits to offer to the industry. I therefore see its expansion in the 80's directed towards land ownership rather than farming.

I apologise for dwelling on the last two points but I do feel they have a direct bearing on the theme of this conference. If, for whatever reasons, farm sizes do not alter greatly, I feel the demand of the future is for the medium hp tractor on the vast majority of farms, although its power will doubtless increase gradually.

2 There is an increasing need to balance husbandry and economics. To me husbandry is number one consideration. Economics must take second place. No doubt with a wider range of crops to choose from, soil structure and the effect that different crops have upon it will become increasingly important.

For example, the advantages of harvesting winter barley or oil seed rape in July when ground conditions are good and allow time for stubble cleaning and sub-soiling, go a long way to making them comparable with, say, sugar beet, which forces growers to harvest at a very busy period with high harvesting costs or face a long campaign in adverse conditions; so I see a continued swing to these crops. They also have the benefit of simplicity of management and the better utilisation of machinery and I see arable units either increasing their specialisation or going to all combine harvested crops.

3 Tractors, being the primary source of power, are obviously, the main item for consideration. By careful planning of cropping policy and by a breakdown of power peaks, economies can be made. When the cropping is decided it is vital to match equipment. We find one of the main benefits of our unit size is the ability to work in gangs and match the equipment used so that work output is similar.

Before I moved up from the basic 70 hp tractors I decided that I could not warrant high hp tractors unless we could justify two, because to use efficiently they need a range of equipment which would not be fully utilised with only one power source. We began by changing two 70 hp for one 90 hp and one 105 hp. We then repeated the exercise to two of each. This gave a reasonable balance, but experience showed that the two largest tractors were not powerful enough so they were both turbo-charged to 130 hp and the two 90 hp's are now unnecessary and will be replaced by medium hp turbo's. But my feelings remain, even on a 1500 acre unit, we are only just large enough to have moved up from the medium hp tractors.

There are several drawbacks to large hp tractors which I feel sure on many farms are not justified and not economic. They have become a status symbol and a very expensive one at that. Their main drawbacks are —

a) High capital cost — 15-20% hp more
b) High running cost
c) High implement cost — anything from 25-50% more per foot of width.
d) High depreciation rate
e) Lack of flexibility — often necessitating duplication to do light work in the summer.

Are they too sophisticated? Most large implements are semi-mounted or towed. Why not pto with high output oil pump and no 3-point linkage?

Looking forward in the short term — apart from the point just mentioned — I feel we should hope to see much improved traction by re-studying the basic Ferguson system and by the development of wheels, tyres, tread pattern and reduction of ground pressure. At the present time, like many other people, we do no field work without twins on all tractors.

Can we hope to see a scrapping of the principle of having to hang weights on the front-end — are there perhaps in the short term, lessons from the fork lift manufacturers — of having hydraulic controlled weight?

I am sure there will be a much increased use of turbo-charging which in many instances could give the mass produced tractors the extra power needed for the larger farms. However, as a result of the recently announced co-ordinated research by manufacturers and government, maybe a completely new concept will emerge by the end of the decade and this move must at a time of expenditure cuts, be greatly welcomed by the industry.

Last but not least — comfort. Personally, I still think the standard of tractor and cab layout is appalling; batteries are inaccessible to inspect and fill, fuel tanks blow back and are not large enough to do a day's work. Why couldn't cabs have better suspension? The old standard Fordson was an

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David L U Scott is a Shropshire farmer.

Paper presented at the Tillage Equipment Design and Power Requirement in the '80's Conference at the National Agricultural Centre 9 October 1979.

easier ride than a modern tractor. Ventilation blasting air straight at your forehead — do the designers not know that hot air rises and that it is the feet that get cold? Rotating seats or some other system to aid watching rear implements — one hopes that electronics will rapidly eliminate the arduous job of looking behind (a sure cause of back problems!) and warning of trouble. Self steering — available in some machinery but would be invaluable for many jobs — eg baling, hoeing, planting, spraying etc.

I feel that manufacturers, in trying to satisfy every market, have ended up satisfying none, and that the current move to offer a basic machine as well as the more sophisticated models is a step in the right direction.

4 In relation to power needs for the future, cultivation is going to decide more than any other operation the requirements in future.

Whilst I feel that minimal cultivation has a place, I do not see it superseding conventional techniques but rather complementing them. The main disadvantage is that the technique requires greater management skill and is more prone to the vagaries of the weather — also the need for a drill to do both jobs. This has been partially resolved with the advent of dual purpose machines, but they need further development for conventional work and they are still very expensive.

The increasing acreage of winter crops is bound to lead to an increase of minimal cultivation. We find our ploughing of winter corn acreage in most instances is expensive and unnecessary provided a good burn is achieved.

With energy costs now such a primary consideration, cultivation must, wherever possible, be carried out by tined and not powered implements unless this is essential. Too often we use powered tools when tines would do, and there is a great deal of scope to further develop means of combining existing systems to suit individual needs, eg Konskilde, Triple K or SKH crumbler.

With the increasing power of modern tractors, there is a tendency for farmers to keep the same implements and travel faster. This must increase wear due to heat generation and breakage, which leads me to another great hope for the 80's, and that is a higher quality steel to be used in the making of wearing parts. I am sure all farmers would agree that to pay extra and obtain a seasons's work out of a set of tines would be money well spent, for it is not only the cost of labour but also very often the loss of several hours at busy times of the year, not to mention the problems created by other implements picking up broken tines.

My last comment regarding cultivation is for the continued development of narrow tines as I am convinced the wide tines have a peeling and smearing effect on our soils.

5 Including drilling as part of the cultivation process, in addition to my remarks about the hopes for the continued development of dual purpose drills, I also hope to see a move towards precision placing if not single seed at least perhaps a wider or split trench, and the placement of fertiliser where research has shown is its best position.

There is also a great need for an improvement in the method of filling drill hoppers which must at the present time occupy 25% of the man's day and a very hard and unpleasant 25% at that. Possibly a tipping hopper now common on potato planters.

6 In conclusion, I would like to make a plea. All the research and development is useless unless it goes hand in hand with several other factors which, on a practical level, can be divided into four categories.

(1) Testing of new equipment and its evaluation. At the moment the RASE and other bodies do their utmost by running working demonstrations and the Silver Medal Competition. Whilst these are excellent in themselves, they are no substitute for a professional testing service, which already exists in Europe. Surely for Britain as a member of the EEC, it should be a major priority of the industry to join with other member countries to avoid duplication and provide a comprehensive testing service at least to evaluate basic information such as is now available to car buyers. Perhaps the agricultural press could do more to provide professional and unbiased comment in the meantime!

(2) Service — I believe now that no new machine is worth considering unless it has an adequate back-up and distribution service both nationally and locally. The opportunity is available to-day to give this with computers, but I feel that the dealers and manufacturers are lagging behind in providing it.

(3) However good the original concept and however well made a machine, more thought must be given to extending the working life of machinery. I know that in this material world, things are not made to last but in agriculture it is vital as is the accessibility of machinery. Guarding and streamlining are all very well but both can be a great hazard to servicing, maintenance and safety, as can lack of information due to poor parts and instruction information.

(4) Lastly, I make one further plea for standardisation, not only in the wide sense such as nuts and bolts but also in the specialist items such as hydraulic fittings etc.

I hope that my rather rambling and personal views have not reduced my paper to a platform for criticism but I feel there will be great opportunities in the 80's with energy now receiving so much publicity and government interest; I know that our agricultural machinery industry is capable, and one hopes willing, to accept the challenge. For as we can see daily, if they do not, there are others only to willing to step in and take their place.

Publishing companies producing books for agriculture are invited to submit new publications for review to:—
The Editor
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Cultivation and soil plant relationships

Robert Q Cannell

Summary

CULTIVATION has traditionally been carried out for two main reasons, to remove weeds and to provide a suitable environment in which seeds can germinate and seedlings can develop. Without cultivation, soil is more compact and while this may be detrimental it does often provide more continuous fissures and channels in some soils to aid infiltration of water, air and root growth.

The likely success or otherwise, of simplified methods of cultivation of different soils can only be predicted in a general way. Knowledge, however, is growing of the soils which can be direct drilled. In the UK the main attraction of simplified cultivation is its speed.

Introduction

Cultivation has traditionally been carried out for two main reasons: to remove weeds and to provide a suitable environment in which seeds can germinate and seedlings can develop.

However, the nub of the problem is that it is not possible to indicate how much cultivation of soil is needed, nor can specifications for seed-beds be produced in any way approaching that in which engineers normally wish to work. Thus there would appear to be a considerable gulf between the users of cultivation machinery on the one hand, including agronomists and soil scientists, and those concerned with development and manufacture of that equipment on the other.

Faced with this long-standing dilemma, but with the growing range of herbicides available to cope with one of the traditional reasons for cultivation it is doubtful if we can do better than reflect on the opening address by Sir Charles Pereira at the ARC/ADAS technical meeting on Reduced cultivation and direct drilling in 1975. He suggested that 'our most logical approach to the whole subject of tillage should start from the observation that, when free of man's interference, most of our soils are clothed with a vigorous system of vegetation which requires no uniform seed-beds'. He also reminded us that tillage can cause deterioration of the soil structure, by oxidation of organic matter, mechanical damage to the structure, including compaction and smearing, thus interfering with movement of air and water, and possibly adversely affecting root growth. Having produced these circumstances, he noted that further mechanical work on the soil is often the only way to try to remedy the situation.

In favourable conditions cereal roots can reach depths of 100—150 cm, and sometimes greater depths, especially in winter cereals. However most of the root system is found in the upper 20—30 cm of the soil (Russell, 1977). When a soil is compacted it is mainly the larger pores that are made smaller. This can have two main effects: (i) since roots are unable to decrease their diameter to enter pores smaller than themselves, the rate of root elongation may be restricted, and a shallow root system can result; (ii) water may drain less freely and the soil becomes poorly aerated, because oxygen can not diffuse into the soil so easily. Oxygen is needed in soil for respiration in roots and soil organisms, and in low oxygen conditions root growth and nutrient and water uptake are all slower. Additionally, in anaerobic conditions the nitrate present in the soil can be denitrified to gases, and the nutrient is lost from the soil. Many soils that are prone to poor aeration are also those most subject to compaction, and so these problems are often interrelated.

With these thoughts in mind, and conscious of the energy required in cultivation, it would seem most appropriate to consider how soil/plant relationships are affected when cultivation is simplified, including its most extreme form — direct drilling. Although the practical possibility of avoiding cultivation is fairly recent and arises from the availability of herbicides, the idea is not. As long ago as 1849 Daniel Lee in the USA described tillage as an 'unnatural operation', and concluded that 'tillage and cropping exhaust land faster than can be done in any way short of carting off the surface soil in a mass' (Bagley, 1973). In a paper summarising a long series of cultivation experiments at Rothamsted in the 1920s and 30s, Keen and Russell (1937) found 'no justification for operations beyond the minimum needed to get a seed-bed and to check weeds until the crop is well established. Work in excess of this minimum, far from increasing the crop, appreciably diminishes it.'

Robert Q Cannell BSc PhD is from the Agricultural Research Council Letcombe Laboratory, Wantage.

Paper presented at the Tillage Equipment Design and Power Requirement in the '80's Conference at the National Agricultural Centre 9 October 1979.

Effects of simplified cultivation on soil conditions and root growth

Soil properties and root growth have been measured in only a few cultivation experiments on a limited range of soil types. Furthermore the effects of continuing different methods of cultivation for several years have been followed in even fewer cases, and much remains unknown. Nevertheless, some trends from work so far are evident. Often investigators have confined their attention to the extremes of ploughing and direct drilling. When measured, shallow cultivation has tended to give intermediate effects.

Surface soil conditions. Many clay soils are self-mulching and this can provide very good conditions for germination in the surface 2-3 cm; self-mulching is most evident in calcareous clays, but is not confined to them. Disposal of straw residues by burning also can aid the formation of stable aggregates in the surface layer (Douglas, 1977). Crop establishment after direct drilling or sowing after shallow cultivation can be much more rapid in dry autumn conditions than when this layer is inverted by ploughing before drilling.

These effects have not been evident in silty soils.

Soil conditions down the profile. The main effects that have been found after direct drilling in comparison with ploughing are:

1. More compact top soil, reflected in greater penetrometer resistance, and smaller total pore space, with a larger proportion of the pores filled with water (Ellis *et al,* 1976; Pidgeon and Soane, 1977).
2. More earthworms and their channels; increases in the numbers of earthworms by a factor of two or three after three successive years have been found in many soils (Barnes and Ellis, 1979).
3. Increased penetration to depth of continuous cracks in clay soils (Ellis *et al,* 1979).
4. More rapid infiltration of water on some soils (Ehlers, 1975; Goss *et al,* 1978).
5. Improved aeration in some soils (Dowdell *et al,* 1979), but poorer aeration on the heaviest soils in wet winters (Dowdell, R J, personal communication).
6. Slower mineralisation of nitrogen from organic matter (Dowdell and Cannell, 1975), and in wet seasons more losses of nitrous oxide gases by denitrification (Dowdell, R J, personal communication).
7. Greater concentrations of phosphorus and potassium in the surface layers of soil (Riley *et al,* 1976; Drew and Saker, 1978).

Root growth Direct drilling generally encourages proliferation of roots in the surface few cms of soil (Drew and Saker, 1978), but below that depth distribution may also be affected. Root growth of spring barley has sometimes been restricted (Ellis *et al,* 1977, Holmes, 1977; Hodgson *et al,* 1977), especially on coarse sandy soils containing little organic matter (Davies, D B, personal communication). In winter wheat by the beginning of stem elongation (in April) the number of roots at 80-100 cm depth can be greater after direct drilling, especially in dry conditions (Ellis and Barnes, 1980); on the other hand in wet seasons on the heaviest soils direct drilling discourages deep rooting of winter cereals.

Root function. In spite of the accummulation of phosphorus and potassium in the surface layers of land that is not ploughed, generally the concentration of these nutrients in the crop has been unaffected, even in dry conditions (Cannell and Graham, 1979).

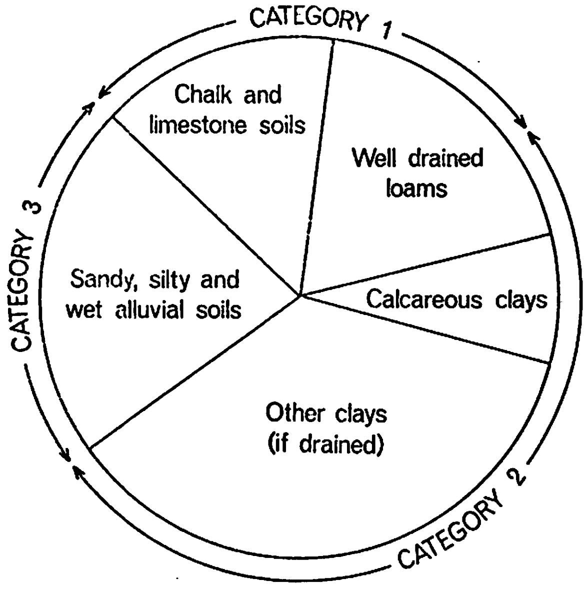
The main exceptions have been less uptake of potassium by winter wheat on a heavy soil, after a wet winter when root growth was restricted (Cannell *et al*, 1980), and in spring crops when rooting has been restricted.

The uptake of nitrogen by winter and spring cereals that have been direct-drilled has tended to be slower, especially in the early stages of growth (Holmes, 1977; Cannell and Graham, 1979). The effect has been most evident on heavy soils after wet winters when rooting was restricted (Cannell *et al*, 1980). This has led to some modification of nitrogen fertiliser requirement. On average in 45 comparisons in the UK additional nitrogen at the rate of 10 kg ha^{-1} was required to give the same yield of winter wheat after direct drilling as after ploughing (Davies and Cannell, 1975).

The deeper rooting of direct-drilled winter cereals in the early spring has facilitated greater extraction of water from depth. In dry seasons this may lead to heavier yields; for example on three clay soils in 1976, crops of winter wheat on average extracted 17 mm more water from the top 100 cm of soil (Goss *et al*, 1978), that was associated with a mean yields increase of 16% (Ellis *et al*, 1979; Cannell *et al*, 1980).

Effects of method of cultivation on crop yield

It is not possible to carry out experiments on all soil types, yet farmers are anxious to know the relevance of different methods of cultivation on their land. Crop yields have been measured in many experimental comparisons of different methods of cultivation, especially for cereal crops, and using this information an attempt has been made to classify soil types in relation to their suitability for direct drilling (Cannell *et al*, 1978) (fig 1).



The proportions of the main soil types in cereal growing areas of England and Wales, classified according to their suitability for direct drilling of cereals (see text for expected crop performance in each category).

The soils are classified into three categories according to the expected crop performance on them after direct drilling as follows:

Category 1 Soils with favourable properties, where yields from both autumn and spring sown cereals are likely to equal those from conventionally cultivated crops. This category includes chalk and limestone soils and well-drained loams, and occupies about 30% of the cereal growing area of the country.

Category 2 Soils where with good management, yields of winter cereals are likely to equal those after conventional cultivation, but yields of spring cereals are likely to be inferior. This category includes calcareous clays (eight per cent of the cereal growing area) and other clayey soils that have been improved by drainage measures.

Category 3 Soils where there ia a substantial risk that yields will be smaller than from conventional cultivation, especially with spring sown crops. This category includes sandy soils with low organic matter content, silty soils and many wet alluvial and clayey soils.

This classification can also be used as a guide for less extreme forms of simplified cultivation since, in experiments, shallow soil disturbance has invariably given at least as satisfactory yields as direct drilling.

Although the large area of non-calcareous clays (about 35% of the ceral area) have been put in Category 2, there is an element of uncertainty about the suitability of the heaviest of these soils for simplified cultivation (table 1), especially when the surface layers are unstable so that ponding of water occurs. However, the difficulties of traditional cultivation on these soils in wet autumns are such that a smaller area of crops may be established; simplified cultivation may in practice be advantageous because of the greater likelihood of establishing the required area of winter crops, even if yields are sometimes less.

Table 1 Comparison of direct drilling and ploughing on yield of winter cereals on two non-calcareous clay soils

	Direct-drilled yield as a % of ploughed treatment	
	Lawford series (35% clay)	Denchworth series (50% clay)
1974-75 (wet winter)	99	82
1975-76 (dry)	111	107
1976-77 (wet)	107	116*
1977-78 (wet)	102	94

* *yield of ploughed crop depressed by more severe lodging (from Cannell et al, 1980).*

Until recently there had been no evidence that crops grown after simplified cultivation could achieve yields equal to those grown after deeper soil disturbance when conditions favour heavy yields. In 1977-78 such conditions existed, and yields of more than 10 t ha^{-1} were achieved in three experiments on clay soils, irrespective of the method of cultivation (table 2). These yields are close to the potential for winter wheat in the UK of about 12 t ha^{-1} (Austin, 1978).

Table 2 Yields (t ha^{-1}) of winter wheat on three clay soils after different methods of cultivation in 1977-78 season

	Direct-drilled	Shallow tined	Ploughed
Evesham series	10.7	10.4	10.1
Lawford series	10.5	10.2	10.2
Denchworth series	9.4	–	10.0

Results are for the nitrogen fertiliser treatment giving the heaviest yield for each cultivation treatment.

Machinery problems that affect soil/plant relationships

Drills With direct drilling, and to a lesser extent with shallow cultivation, success depends on thorough removal of straw (Ellis and Lynch, 1977). Unless this is achieved, the residues may impede the drill and also seeds are likely to be buried in contact with straw residues that may produce toxic substances in anaerobic soils. Germination and plant establishment can be restricted, especially in wet autumns, when the advantages in timeliness of simplified methods of cultivation for establishing winter cereals are potentially greatest, and yield depressed. New direct drilling equipment, such as that being developed at the Scottish Institute of Agricultural Engineering, which avoids placing the seed in contact with straw residues may help to overcome this problem. Chemical treatment of seeds may also help to alleviate the problem. Direct drilling is still a relatively new procedure and further developments in drill design can be expected. Nevertheless, some of the recently introduced drills in this country and overseas are able to give satisfactory results in many conditions.

Most experiments on simplified cultivation have been concerned with cereals or other surface-harvested crops. However, important work is in progress at the Norfolk Agricultural Station where strip tillage for sugar beet in rotation with cereal crops is being studied; early results are encouraging (McClean, S P, personal communication).

Compaction Direct drilled land is often more resistant to compaction and thus more trafficable than land that has been ploughed, but many of the clay soils are easily deformed when wet and there is the possibility of cummulative effects of wheel damage; without cultivation there is no opportunity to counteract these effects. Compaction by combine harvesters may be one of the worst causes of this problem. The need for low ground-pressure vehicles to minimise compaction in simplified cultivation systems has recently been discussed by Elliott (1979).

Drainage Assessments of simplified cultivation on clay soils have been made on land drained according to recommendations for ploughed land. However in view of the effects on soil physical properties the drainage requirements may depend on the type of cultivation. The top soil of direct-drilled land has a smaller total pore space and possibly smaller hydraulic conductivity than ploughed land. If so, the lateral movement of water to drains is likely to be somewhat impeded. On the other hand, the presence of earthworm channels and cracks between pods that are not destroyed annually by ploughing can substantially aid infiltration of water. As yet the relative extent of these effects on the drainage of heavy land is not fully understood.

Subsoiling There seem to be many soils where, for cereals, especially sown in the autumn, little soil disturbance is necessary (apart from drainage operations, including mole drainage). Nevertheless on some soils in some years compaction may be unavoidable especially where root crops are grown in mixed rotation with cereals, eg after harvesting in wet seasons. Furthermore, as already noted, some soils are unsuited to direct drilling and may benefit not only from cultivation, but possibly from a simultaneous deep placement of nutrients, particularly the immobile nutrients such as phosphorus. Until recently suitable machinery has not been available. In an experiment where subsoiling in a sandy loam was carried out by hand, with and without deep placement of P and K, the benefits have recently been described by McEwen and Johnson (1979). The treatments were applied once in 1973, and over the following four years subsoiling alone increased the mean yield of winter wheat by 21%, barley by 24%, and sugar (from beet) by 11%; potato yields were not affected. Incorporating P and K into the subsoil did not affect wheat yield, but increased the mean yield of potatoes by 16%, and further increased barley and sugar by 20% and four per cent respectively. The reasons for these effects are unknown. Machinery such as the winged subsoiler (Spoor, 1975) and the Wye double digger (Warboys *et al*, 1976) that can disturb subsoils to a greater extent than conventional subsoilers, and be adapted to place nutrients at depth will enable these procedures to be more readily and widely evaluated.

Conclusions

1. Without cultivation soil is more compact, and although this may be detrimental, in the absence of cultivation greater earthworm activity, more continuous fissures and channels in some soils can aid infiltration of water, aeration and root growth. As yet, however, the likely success or otherwise of simplified methods of cultivation in different soils can only be predicted in a general way. This is partly due to the inability to measure soil properties that affect root growth. Furthermore restricted rooting may not affect yield in all years.
2. Direct drilling of spring cereals is likely to be successful on chalk and limestone soils and well drained loams, and of winter cereals on these soils and also on clays where drainage is satisfactory. Direct drilling is least likely to be successful on coarse sands low in organic matter, in wet soils and in weakly structured silts; on the latter, shallow cultivation may be sufficient to give yields at least equal to those after ploughing.
3. In the UK the main attraction of simplified cultivation is its speed, enabling a larger area of heavier yielding autumn sown cereals especially winter wheat to be grown, and sown early enough for maximum yield.
4. Experiments in many countries point to the possibilities of simplifying cultivation without loss of yield. Although Keen and Russell stated more than 40 years ago that 'We have been driven to revise our views' (on the possibility of simplifying cultivation), there is still scepticism about the applicability of new methods now possible. Systems involving shallow cultivation may be more readily adopted than the most extreme of direct drilling. Experiments now in progress should assist in clarifying where the techniques are most appropriate.
5. Improved direct drills and means of minimising compaction during all field operations will be important in further adoption of simplified cultivation techniques.
6. The role of subsoiling and the deep placement of nutrients in any cultivation system has not been adequately assessed. New machinery should now make this possible.

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Cultivation systems in the '80s

Dr D Bryan Davies

Summary

SEEMINGLY contradictory trends may always have arisen in cultivation practice and certainly for the coming years there is no shortage of such options. For the first time we see implements which can comprehensively loosen subsoil whilst at the other extreme more farmers grow crops without cultivation year after year. The reconciliation of these extremes has to be in terms of crop species and soil condition, but many farmers are ill prepared to make the right decisions even though large investments are at stake.

Other developments in which engineers have an important part to play are more effective cultivation of wet soils, reduction of compaction, establishment of crops in straw residues and strip tillage systems for sugar beet production and wind erosion control.

Substantial changes in both opinion and practice have taken place in UK cultivation during the last decade. A reformation is not too strong a description for this change, and the opening of closed minds that have accompanied this process needs to proceed much further. Inevitably changes bring both advantage and failures, and a lack of appreciation that radical changes in cultivation have an effect on virtually all important aspects of farming is often responsible for lack of success.

At no previous time has the arable farmer had so much freedom of action in his choice of cultivation. Power need no longer be a limitation; the bewildering array of tillage implements increases each year; methods of weed control other than tillage are well developed; rotational restraints are less rigid and a bewildering range of ideas on optimum cultivation are discussed and practised. Combine this freedom of action with both the unique requirements of individual farms and the great range of soil conditions in the UK and we can appreciate the dilemma encountered by informed farmers.

The questions to which answers are required are: what principles are there to guide us in choice of cultivation system, and by applying these principals in what ways can we suggest that cultivation systems may be improved or replaced by better ones?

The following is a list of general statements that apply in most arable situations and encourage flexibility rather than rigidity:

i Cultivations have both beneficial effects (loosening, tilth production, burial, firming etc) and adverse effects (compaction, smearing, production of clods, moisture loss etc). The good effects must be maximised and the bad effects reduced.

ii Any cultivation is unnecessary unless it reduces a limitation on crop production. Therefore the minimum of cultivation to ensure a good crop should always be the aim.

iii Cultivations alone can rarely create good soil conditions from poor ones, but they are valuable in promoting the process of improvement.

iv Good healthy crops and strong biological activity in the soil are the best conditioners and valuable aids to weed supression.

v Moisture stress is the commonest cause of yield depression in lowland arable England provided good husbandry and adequate drainage are present. Consequently we should always try to ensure that roots exploit the soil to depth.

Soil type and cultivation

There are several hundred soil types in Britain all with different potential weaknesses and strengths but for the purposes of this paper we need only recognise two types. Those which present very few physical problems and for which choice of cultivation is largely independent of soil limitations and a larger group, for which soil properties and behaviour constrain choice of cultivation. The actual group into which a soil falls will vary on the crop grown and on its sensitivity to soil conditions.

Cultivation for cereals

Direct drilling and annual cultivation to a depth below the topsoil are contradictory extremes that are currently canvassed. Between these extremes we have shallow cultivation by tines, mouldboard ploughs or rotary implements and deeper cultivation using tines or mouldboard ploughs.

Choice of cultivation depth

The factors determining choice of cultivation should be weed control, freedom to burn straw, available time and most important of all, soil examination in each field. We know that cereals do not require fine tilths and finely fissured topsoils to give optimum yields and that spring cereals require rather better soil condition than winter cereals. Consequently for winter cereals there are very many situations when little or no cultivation will be needed. However, we should beware of compaction below shallow cultivation depth, which can and does build up on the more difficult soils, and which can and will reduce yields in some years. The same precaution applies to direct drilled land where heavy traffic has been used on moist soil.

Where severe compaction is identified in the topsoil progressively deeper cultivation should be employed to remove the dense layers particularly if they are present in soils which do not shrink appreciably on drying.

Engineering requirements

Engineers have already made large contributions to minimum tillage systems and to direct drilling, but more is urgently required if the techniques are to be used more widely and more reliably. The topics requiring sustained development are:—

i The reduction of soil compaction by wheels.

ii Techniques of minimum tillage under straw mulch.

Dr D B Davies, ADAS, Cambridge.

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iii Loosening compacted clay topsoils without producing large clods.

iv More reliable systems for establishing crops by broadcasting.

There are many views about how to tackle these problems and often the technology is available to achieve them, but they all require sustained input by engineers working closely with soil and agronomy specialists if progress is to take place.

A further limitation of minimum tillage is how best to apply the system on farms with above ground break crops. This topic has so far received only limited and piecemeal attention.

Deep soil loosening

The subsoiler has been used in Britain since before the start of this century and in the right conditions can improve crop yield dramatically. Recently there has been an upsurge in interest in subsoil loosening; the catalysts have been Spoor and Godwin working at Silsoe, Warboys and Gooderham working at Wye with the double digger, the application of German techniques on Essex marshes and the Howard Paratine. Farmers are now asking themselves if we should be moving towards direct drilling or towards deeper and deeper disturbance. Naturally many feel confused by this situation, but in fact the principles stated earlier allow for a rational choice to be made. These soils which have substantial compaction at depth need to be improved and once improved should be cultivated to the minimum depth for the crop. This process of improvement may require one, two or more years of deep loosening, depending on the soil condition and the machine in use.

Those soils not requiring subsoil loosening will not benefit, and soil examination is the obvious first step in making this assessment.

Engineering requirements

Tools to loosen subsoil fully have become available only recently. Engineers should be encouraged to develop further various types of implement including those based on vibrating and rotary tine. Equally important the engineers, soil scientists and agronomists need to test the effectiveness of these machines at relieving particular subsoil conditions and to determine the extent of loosening required in different circumstances. Response to fertiliser placed in the subsoil is a further requirement of this complex area of work which requires thorough investigation.

Effects in practice

Whether or not these techniques will be applied to the general advantage of farmers in the future will depend on how well individual farmers are able to establish a need for subsoil loosening and then how well they master the techniques of loosening, but there is little doubt that the machines will continue to be misused unless farmers apply themselves more assiduously to the task of assessing their subsoil and the effects of subsoilers.

The role of roots and earthworms in stabilising loosened structure and producing additional coarse pore space is an important aspect of soil improvement, and should not be overlooked.

Sugar beet and vegetables

Crops in this group are more sensitive to topsoil conditions than cereals and direct drilling has little application for most of them. These crops present an opportunity for reducing secondary cultivation, for confining compaction to uncropped areas of land and for reducing the damage sustained during harvesting.

Although the case for minimum seedbed work in the spring has been amply demonstrated at the Norfolk Agricultural Station, far too many farmers still traverse their sugar beet land relentlesly in the spring with the net results of cloddier tilths, slower root development and moisture loss from seedbeds.

Curved spring tine harrows are still very widely used seedbed tools although all the evidence indicates they are inferior to the straight tine harrow.

For far too many years farmers have had to put up with sodden battlegrounds during wet autumns without enough attention to the problem from engineers. The bed system for vegetables has been used with success for several years but a problem is that the interbed wheelings are set out on cultivated land and rut deeply in wet soil. Recent work at the Norfolk Agricultural Station has established sugar beet in six inch cultivated strips cut into overwintered cereal stubbles. This technique when developed will provide three advantages:

Good conditions for crop emergence and root growth.

High bearing capacity for tractors and harvesters running on the uncultivated stubble.

Control of wind erosion on vulnerable soils.

Provided engineers and agronomist's give a sufficient lead I believe we shall see many more farmers growing beet and vegetables on land untouched by wheels throughout the year. This will be achieved either with wide wheel base implements capable of cultivating, fertilising drilling spraying and harvesting within the cropped area or by systems developed from the work of the Norfolk Agricultural Station.

Compaction

For those farmers who suffer compaction problems and they include a very wide range of farmers on clays, silts and sandy soils, prevention is better than cure. Lower ground pressures, skeleton rather than rubber wheels and wheels on permanent alley ways are alternative or complementary means of achieving lower compacting pressures. It is not enough for the engineers and agronomists to present these alternatives; we need to develop them into commercial systems. This is perhaps rather tedious unspectacular engineering but an important task for the present and future.

Conclusion

The number of options open to the cultivator of soil has never been larger. Several of these options seem contradictory but when considered in the context of soil conditions they are seen to be facets of a coherent whole. Many of the current spate of cultivation options have stemmed from the ingenuity and initiative of the world wide tillage industry; often it is large numbers of implements to choose from rather than the lack of alternatives which causes difficulty. However, little practical impact has been made on ways in which farmers can avoid compaction in land and this is severely restricting the reliability of shallow cultivation techniques and direct drilling on less stable soils. The time has come I believe to call a halt to the development of unnecessarily powerful tractors and to devote more talent to devising ways of avoiding the annual chore of undoing the damage inflicted by wheels during previous years.

Finally, if farmers are to use minimum cultivation systems and subsoil loosening machinery effectively, they will have to find time to develop the skills of soil examination and interpretation. This was the main message of *Modern Farmer and the Soil* and it is even more true today.

Research into Powered Cultivations

D P Blight

Summary

POWERED cultivations are desirable as they offer a means of fuller utilisation of tractor power; power may be applied to the soil in two principal ways; by rotary and by vibrating tines. Rotary cultivation may be by either forward or reverse rotation of tines, each having its merits.

The question of blade shape is as fundamental as the direction of rotation of the rotor and deserves more research effort.

Another field for research is the effect of the ratio of working depth to rotor diameter, together with the need to study the effect of all these factors on soil breakdown.

A reliable means is required for correlating, in precise terms, cultivation to subsequent crop performance. Throughout these investigations the importance of fuel economy must be borne in mind.

Introduction

At the outset it may be pertinent to enquire, powered by what? We have all had the lessons firmly rammed home that fuel oil can be increased in price by frequent and sizeable steps, and that supplies can be capricious. Incidentally, one notes that the EEC countries intend to keep annual oil imports in the period 1980-85 at no more than the 1978 level, supposing that level of supply could be maintained, so we could not plan an increased usage, even if we were optimistic enough to want to. However, although demand for oil is outstripping supply, it is to be expected that, in the decade under consideration, the farmer will still be using oil-powered tractors, though the cost of the fuel (and probably of the tractor) will, in real terms, be substantially above that obtaining at present. You may think the continuation of oil-powered tractors a reckless assumption, but we have no choice in the matter: nothing else is available. Research, however, or at least some research, should concern itself with a timescale longer than the decade immediately following, so research in the 80's will be for adoption in the years beyond that. What, then, of the prime mover for the late 80's and the 90's? By this time we really must have made up our minds on the type and supply of fuel for vehicles in the post oil-well economy. By making a start *now* it may be possible to have the capacity to produce practicable quantities of liquid fuel from coal before the 21st century, if that is going to be the solution. The construction of the necessary plant will take many years, and arrangements must be made for the supply of adequate quantities of the feedstock, coal. Alternatively, engines like the Stirling, less dependent than the internal combustion engine on the type of fuel required, may have been shown as the probable way ahead. The fuel cell, the great hope of a decade and more ago, seems to have become relegated to a minor role, the question of the fuels to use, and their origin being, apparently, far from settled.

Whatever type of prime mover is finally selected, farming may be expected to adopt those units developed for the transport industry, rather than attempt an independent solution.

The flexibility offered by an automotive prime mover, such as the tractor, over alternatives such as winch cultivation, encourage the assumption that, whatever the energy source used, something offering much the same type of general service as the present-day tractor will ultimately be evolved. In my opinion, it is justified on these grounds to consider that powered tillage tools do have a future, and that research into equipment driven from the tractor by pto, hydraulic unit, electrical generator or other means is worthy of further effort. I take a rather cautious view of the types of powered cultivator likely to be investigated, expecting developments of existing types of powered cultivator, rather than novel concepts, to be the likely pattern in the period under consideration.

Degree of cultivation necessary

The reasons why we work the soil have been critically re-assessed over the past few years. A generation ago the matter would scarcely have been debated, (although one still remembers the furore created by *Ploughman's Folly* (Faulkner, 1943). The control of weeds was of itself an adequate reason for soil cultivation, to which would have been added a comment that it was also necessary to cultivate soil to provide the proper conditions for seed to germinate and crops to flourish. Herbicides now offer an alternative means of weed control and thus more attention can be paid to the establishment of soil conditions favourable to the crop to be grown. Papers given at the ADAS: ARC Symposium on Maximising Yields of Crops (ADAS/ARC, 1979) describe investigations into many aspects of factors affecting growth, but nowhere is an attempt made at a precise definition of the optimum soil physical conditions (porosity, hydraulic conductivity, spectrum of crumb size, etc.) for any crop, though praiseworthy attempts have been made by Edwards (1957a, 1957b, 1958) and Hammerton (1961) to assess the effect of crumb size on crop establishment and growth, and Dexter (1977) has proposed one generalised method of describing soil structure. A precise specification of the soil condition required for the optimum growth of any particular crop is simply not available and it may, indeed, be doubtful whether it would be of particular value. Thus the precise aim of cultivations may be rather obscure in parametric terms. Although Russell (1949) was not able to demonstrate a relation between subjective assessment of soil tilth and subsequent cereal yield, an experiment by Pascal (1977) showed a marked degree of success. Thus we may feel that situations exist where practical agronomists can recognise by experience the soil conditions they require.

While there is then, a demonstrable need for cultivations of some type, why powered cultivations? Powered cultivations offer means of the fuller utilisation of tractor power. So long as tractors are used solely as mechanical draught they are merely substituting for the horse team; power and rate of working are lost through wheelslip, and the opportunity to exploit alternative methods of working the soil is foregone. Powered cultivations offer potential improvements over cultivations with passive tools.

Type of powered cultivator

Power may be applied to soil cultivating tools in a number of ways, the two principal types being rotary and vibrating. A few digging machines have been produced from time to time, among the most recent being the rotary spade machines. With the exception of the NIAE rotary digger (Chamen and Cope, 1974) — though this could be considered a special type of rotary cultivator — the rate of work tends to be low and little has been heard of digging machines recently.

It is appropriate to review the situation we have currently reached in research into the various types of powered tool to form a starting point for consideration of the direction which future research might take.

Rotary cultivator

First let us consider the rotary cultivator. Much recent research has been conveniently reviewed in a series of papers by Hendrick & Gill (1971a,b,c, 1974, 1978) and the conclusions proposed are summarised in the following paragraphs.

One fundamental parameter of rotary cultivator design is the direction of rotation of the cutters. This has been reported in a number of papers, usefully collated in the first paper by Hendrick & Gill (1971a). After some analysis of the geometry of the cutters, the authors show the need to differentiate between the energy required to rotate the cutting unit, and the total energy requirement, which includes that needed to move the machine forward. They also point out that information on soil breakup in these experiments, the reason for the operation, is often poorly reported or even absent. In general, it would seem that rotating the cutting elements in the "reverse" direction, i.e. counter to the direction of motion which would assist the machine to move forwards, can decrease the cutting force required compared with cutters rotating in the "conventional" direction. Better depth stability and reduced tool breakage were also observed. Various figures have been quoted for this decrease, but the investigations from which they are derived are not entirely comparable; Grinchuk & Matyashin (1968) suggest an average factor of reduction of 1.5. However, the

D P Blight MSc (AgricEng) PhD CEng MIMechE is from the Scottish Institute of Agricultural Engineering.

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relationship between depth of working and the radius of the cutting unit is important, and under some conditions reverse rotation may require more energy. By taking into account the energy required to move the machine forward, the picture alters; the difference between the contribution towards forward motion made by the blades turning in the 'conventional' direction, and the resistance to forward motion by the blades turning in the 'reverse' direction shifts the balance generally in favour of 'conventional' motion. Furlong (1956) showed that for a variety of shapes of rotary cultivator blade 'reverse' rotation generally required 70% more power, on average, than 'conventional' rotation, because the latter assists in moving the machine forwards.

The overall effect of reverse rotation on soil pulverisation is poorly established, although it is reported that the effect of throwing the soil forwards can be troublesome. On balance it seems that reverse rotation results in a generally larger clod size.

The importance of the depth of working in relation to the radius of the rotor is reviewed in a second paper by Hendrick & Gill (1971b). The conclusions reached were that increasing the depth of tillage increased the total power requirement of the tool, but in general reduced the specific power requirement (ie power required/unit volume of soil disturbed). The ratio of rotor diameter to depth which achieves the minimum specific energy requirement appears to lie in the range 1.1 to 1.4. Hendrick & Gill's (1971c) third paper reports on the ratio of peripheral to forward velocity. Again other published reports are summarised, with the warning that comparisons are difficult because many factors are not comparable between investigations, soil type and condition for example. However, some results suggest that it is possible to calculate a bite length requiring a minimum value of rotor power. If the ratio of rotor peripheral speed to forward speed = λ, then reducing λ by increasing the forward speed increases the power requirement, but decreases specific power, while reducing λ by reducing the rotor speed decreases both power requirement and specific power. The effect on final clod size of alterations in λ is not established.

The question of blade shape, though as fundamental as the direction of rotation of the rotor, has not received the attention it deserves. Hendrick & Gill (1971a) refer to Furlong's (1956) paper, where results of tests of various types of 'L' and 'C' shaped blades are reported. On the basis of power input the 'C' shaped blade rotating in the 'forward' direction was the most economical. Investigations of various parameters affecting the design of the conventional 'L' blade were made by Söehne (1957). For the one soil, at the single moisture content which he used, Söehne showed that the power input per unit volume of soil decreased with increasing width of the tool, that less power was used in soil shear than in soil cutting, that tool rake angle was unimportant, but that tool cutting angle had an optimum of about 20°. The effect of the radius of the corner of the 'L' was that increasing the radius decreased specific power consumption up to a radius of 30 mm, but had little further effect beyond that value.

Perdok & Burema (1977) also investigated the power requirement of a rotary cultivator with 'L' shaped blades, and arrived at the empirical relationship

$$T = q.N.B.L. + r.\ B.L. + s.N^2 + t$$

where T = rotor torque for a given depth of work,
N = rotor speed
B = working width
L = bite length

q, r, s, t are arbitrary constants determined from the experimental results.

So much, then, for what we know of rotary cultivators. What further information do we need?

First and foremost, we have the perennial problem of insufficient information on the effect of soil type and soil moisture content, and probably of soil organic content too, on the performance of the machine. Ideally we should seek a generalised solution which will enable these effects to be calculated from a minimum amount of field experimentation. Until this solution has been found, much more experimental work will be necessary.

The effect of the ratio of working depth to rotor diameter seems to be another fundamental parameter which has been inadequately reported, while the important criteria for the design of the cutting tool seem scarcely to have been touched on. Another fundamental is the need to study the effect of all these factors on soil breakdown, and to relate this to the amount of soil working necessary for the growth of each of the crops of interest. There is plenty of work there to carry researchers through the next decade.

Vibratory tillage

Under this heading it is intended to consider vibration of the tool in the direction of the forward motion of the implement, or in the the vertical direction, or a combination of the two. The operation of the vibrating harrow used for secondary cultivation is rather different, and has been analysed by Kofoed (1969).

It has long been known that the force required to pull a tine through the soil can be greatly reduced if the tine is vibrated. Work must be done on the tine to vibrate it, but it was thought that suitable operating conditions could be devised which would lead to an overall reduction in power input to the tine. Unfortunately this has not proved unequivocally to be the case. Spectacular reductions in draught have been recorded up to 80%, ie only 20% of the draught of a rigid tine may be required under certain conditions if the tine be vibrated. However, the total power input to the tine may be 800% of thar required by the unvibrated tine.

The reason for draught reduction being achieved by vibration has been the subject of some speculation. One proposal is that in sandy conditions the soil in the vicinity of the tip of the tool is fluidised by the vibration, ie it behaves rather like a liquid, and the passage of the tool is thus facilitated. For clay soils a different mechanism has been proposed, that the vibration causes free water, and even chemically bound water, to migrate to, and soften, the soil in the vicinity of the tip of the tool, so lubricating the passage of the tool. While these phenomena may occur (the migration of soil water round a vibrating tool has been reported elsewhere) it is proposed by Benington & Butson (1974) that they are second order effects and that the phenomenon of draught reduction by vibration is most simply explained by force averaging.

Several models of the soil-cutting process for fore and aft vibration of the tool have been proposed and reviewed by Benington & Butson who conclude that those based on Blekhman's (1954) soil model most accurately reflect the situation encountered in practice. Of these models, that of Boyd & Nalezny (1967) most accurately predicts draught reduction. There is, however, a dearth of reliable information on which to base a model of total energy requirements.

The model proposes that the ratio of peak tool speed (assuming simple harmonic motion) to the forward speed of the implement carriage be expressed by a factor α. If α is less than unity the vibration of the tine will cause it to move backwards more slowly than the forward speed of the carriage, and the tine will always remain in contact with uncut soul. Under these circumstances it is assumed that vibration will not give any reduction in draught. If α is greater than unity, during a cycle of vibration the tool will move backwards through already cut soil at one stage, providing a thrust in the forward direction. The tine will then move forwards through already cut soil until it reaches, and cuts, fresh soil. The rate of draught reduction on the basis of this model is very rapid at values of just greater than unity, but quickly falls off. The practical range for α is probably about 1.5-3.

Oscillation in a vertical direction has been less well researched; Shurenko (1958) compared oscillation in this direction, and concluded that fore and aft oscillation had an effect 1.5-1.6 times greater than vertical oscillation.

Shkurenko's paper is of further interest because it is one of the few to include oscillation other than by a crank mechanism. Using a crank to oscillate the tine constrains it to adopt the amplitude built into the mechanism. If, however, oscillation is induced by the rotation of an unbalanced mass attached to the tine, the amplitude of oscillation will assume a value depending on the immediate operating conditions obtaining. There seems to be some slight evidence that oscillating tines using this principle may be rather less energy demanding than those using a crank mechanism.

In all this work the effect of the tool on soil physical conditions has not been adequately examined. Research in the next decade, therefore, might, with advantage, address itself to the following points:—

1. Extend existing models of vibratory soil cutting to give a realistic estimate of overall power input. (This work is already in hand).
2. Investigate more fully the use of 'out-of-balance weight' vibrating mechanisms (a start has already been made on this).
3. Examine the effect of vibratory tillage on soil physical conditions.

It is, however, already clear that vibratory tillage techniques will be limited in their application to situations where a rigid tine would require a high draught, for example some drainage operations, or leave an undesirable surface disturbance, for example, laying telephone cables over established lawns without damaging the turf unduly.

Other powered cultivations

Power has been applied to cultivating equipment in other ways, the reciprocating harrow, and cultivators with tines rotating about a vertical axis come immediately to mind. Some of these tools, in common with much other soil-engaging equipment, may suffer from a high rate of wear of the tines,and careful attention to the selection of the materials from which they are made is likely to be rewarding. It is known that interesting new materials are being examined for applications such as this. Optimum tine: forward speed ratios for effective soil working and fuel economy also form an appropriate area for future research since little has been published on this subject.

The advantages which may follow subsoiling are of increasing interest. A development of powered subsoiling equipment is the Wye double digger which combines a driven rotary subsoiler with a conventional plough (Warboys *et al*, 1976). Simultaneous ploughing and subsoiling using passive tools, has been practised for many years, but once problems such as the low rate of work have been overcome and the necessary degree of subsoil breakup have been established, further development of powered tools of the Wye type may be expected.

There remains a category of powered cultivation tools which almost defies classification. Ploughs with powered components form the most popular items, and these may fill an important local need (e.g. where soils scour poorly). Other advantages claimed for rotating mouldboards have been better power utilisation, better burial of surface trash, and better soil mixing (MacIntyre, 1972). Other applications of power to ploughs include lubricating the mouldboard by compressed air (Kitani, 1978) and attempts to achieve the same end by migration of soil water by electro-osmosis, a process which seems too slow to be of practical value. Research in areas such as this is governed by the fertility of the inventors' imaginations, but its future must be bound up with the future of ploughing, which is expected to be debated with sharper emphasis over the next decade.

Research linking input and soil working

It will have become apparent by now that this paper is urging for research into the power input of cultivating machinery to be much more precisely related to the effectiveness of the use of that power in producing the soil conditions necessary for crop growth and for closer definition of those conditions. This paper earlier proposed that neither the range of soil conditions necessary, nor the optimum soil conditions for any crop, were specified with adequate resolution. Nevertheless, it is important to attempt to show that relationships between power input, soil condition and crop growth can be established. This has been stated by Pascal and others in unpublished work at SIAE, comparing various types of equipment in cultivation trials for potatoes on a clay loam.

Specific workrates in ha/kWh were measured for a variety of cultivation implements, some passive, some powered. The yield and the distribution of clods were measured in the seedbed, and again at harvest, and the effect of weathering noted. The yield and the size distribution of the potato crop for which the cultivations were preparing were also measured. This work indicated that some types of powered implement used power more effectively than others to produce adequate tilth conditions for potato harvesting. An extension of the work suggests circumstances under which more work might have been done on the soul with advantage, and others under which less work (and thus less expense in cultivating) may' not have detracted from the value of the crop grown.

Conclusions

Over the past two decades much work has been published on features of the design of powered cultivating equipment. So vast is the area of work, however, that many fundamental features, such as the optimum shape of the tool, have not yet been firmly established. To a large extent the difficulties of research into cultivation equipment stem from a lack of precise knowledge of the soil conditions which cultivations are required to produce. Means of relating cultivation performance to subsequent crop performance in precise terms are the outstanding research need.

The problem of fuel supplies increases daily, and if disaster is not to overtake us all, an answer must be ready for implementation by, at the latest, the end of the decade under consideration. Studies of operations leading to the best use of fuel in food production must be a priority with all of us now, and the selection of appropriate cultivation techniques offers an area of potential saving.

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The power requirement for tillage in the next decade

John Matthews

Summary

THE necessity for low production costs in the face of rising fuel prices will surely compel farmers to adopt tillage practices which are less power consuming than present methods.

Accurate prediction of cultivation power in the '80's is not feasible but certain trends can be foreseen, including the take-up of currently existing techniques which can reduce energy input by 50%, the probable development of new wheel equipment, the development of seeding equipment which does not require tractor draught and the early stages of controlled traffic systems.

Introduction

The scenario set for crop production in the remaining years of the century is one of increasing sufficiency of yield in Europe, even if changes are developed in the bread making process so that more European wheats may be used rather than the imported harder varieties. With a sufficiency of crop, the pressure to produce it at lowest cost to maintain market competitiveness must inevitably increase. Added to this, it is predicted that the relative cost of fuels is likely to double before the end of the century — with some forecasts of a three or even four-times re-valuing. These two factors surely will compel farmers to adopt less power-consuming tillage processes, probably in combination with improved attention to precision of work where relevant. For example, less comprehensive soil inversion and soil stirring to encourage weed germination as a prelude to killing weed plants, will inevitably mean that weed control by chemical or mechanical methods must be carried out with greater care. Water drainage from surface soils will be less, so that greater care will be needed in soil levelling and in avoiding wheel or tool induced compacted layers which cause wet patches in arable fields.

Although most of the analysis in this paper is attempted in units of energy or power, it is considered more likely that fuel will be 'rationed' by price than by permit, so that it is essential to consider the options in economic terms as these will more probably govern the choices made by farmers. This implies a consideration also of the labour requirements of the techniques available today and of those standing as potential developments. With a particular size of power unit, labour and fuel costs tend to be correlated since an energy-intensive task takes more time to complete. When vehicle and implement type are open to choice and to future considerable changes in design, this link may be much less marked.

The most difficult assessment in a paper of this type is of the rate of take-up by farmers of novel tillage equipment which may be developed. The author therefore attempts to show below only the potential changes in power requirement for tillage and for sowing of seeds and to present this power requirement in terms of tractors or vehicles of less traditional types with appropriate power ratings. Ways of ensuring that this power is used with high efficiency are also discussed.

Space does not permit discussion of the many details of crop husbandry which must be correct if the reduced energy techniques are to succeed. It must be stressed however, that there would be little scope for engineering developments of low energy tillage methods without the skills of the users to maintain a high level of husbandry.

Analysis of present use of power

As has been pointed out at recent Institution conferences, agriculture uses about four per cent of the nation's consumption of primary energy[1]. A breakdown of this shows three of the larger components to be petroleum fuels 24%, machinery 14%, and fertilisers 23%. These data may then be further analysed to obtain values of the energy inputs for tillage and planting processes as shown in table I. Fertiliser components are also included for comparison. Nationally the growing of cereals is the most significant economically so that this will be used for later comparisons. The totals for the various crops in table I may be added with further addition of seven per cent for tillage for grass and minor crops to obtain the energy totals in table II. The further breakdown in table II of the fuel energy to show that available for the tillage implement against that lost in the internal combustion engine, the tractor transmission and traction losses shows how relatively inefficient is the power process. Within the implement further large losses are apparent. Each of these non-productive components represent an opportunity and a challenge for efficiency improvement.

Table I Primary energy inputs for U K arable crops

Crops	*Cereals*	*Potatoes & beet*	*Field vegetables*
MJ/ha			
Primary tillage	700	750	1000
Secondary tillage & seedbed preparation	300	1000	500
Planting, etc.	200	250	400
Approx. area of crop, ha	4	0.4	0.25
Total energy, TKJ			
Primary tillage	2.8	0.3	0.25
Secondary tillage & seedbed preparation	1.2	0.4	0.1
Planting, etc	0.8	0.1	0.1
Fertiliser	26.5	5.2	3.5

Table II Approximate analysis of energy used in tillage for all crops in the U K

Item	*Energy TKJ*	*Efficiency*	*Proportion*
Primary tillage	3.7	–	–
Secondary tillage & seedbed preparation	1.8		
Planting	1.0		
Total for tillage (T)	6.5		
Traction efficiency (E_1)		0.6	
Energy at axles ($\frac{T}{E_1}$)	11.0		
Transmission efficiency (E_2)		0.9	
Energy from engines ($\frac{T}{E_1 E_2}$)	12.0		
Engine efficiency (E_3)		0.24	
Fuel energy ($\frac{T}{E_1 E_2 E_3}$)	50		
Petroleum fuels used on farms	85		
Proportion on tillage			59%
Energy available from U.K. tractor parc*	72		
Proportion on tillage			17%

* *Calculated from 400,000 tractors x 50 kW mean x 1000 h/annum x 3600 J/kW.*

Beyond the mechanical losses, power is used to shear and to move soil to a degree in no way related to depositing a seed at an appropriate depth, ensuring that the soil structure permits adequate transport of air, water or nutrients and that it is penetratable by the plants' roots.

It is interesting to compare the energy input figures with the power available from today's UK 'parc' of tractors on the assumption that each tractor is capable of 1000 hours use per annum. For tillage the planting, which probably represent of the order of 40% of the demand on the tractor fleet to actually use only 15-20% of the power available again clearly demonstrates the

John Matthews is from the National Institute of Agricultural Engineering.

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opportunities for change, even accepting the other factors governing tractor design and tractor fleet size, which are outside the scope of this paper.

Analysis of present economic factors

This section although limited to cereals may probably be taken as a pointer to other crops.

Costs of two existing methods of tillage are compared in table III. In relation to the total input costs, those of the machinery, fuel and labour do not dominate. However, where these techniques are applicable costs of the most economical primary tillage methods are only a little over a half of those of traditional ones and they may also increase a typical net profit margin by £10-12 per hectare. Patterson's work at NIAE[2] shows that such advantageous methods may be employed without reducing the yield on a wide range of soils and with autumn and spring sowing (fig 1). These conclusions validate the present trend towards reduced power tillage. To emphasise further the need for this trend continuing or even accelerating, figures are also included in table III with fuel costs hypothetically increased by two and by four times from present levels.

Table III Some typical costs of winter wheat crop establishment, £/ha

	Item	Traditional techniques	Reduced cultivation
Materials	Seed	34	34
	Fertiliser	42	42
	Sprays	30	30
	Total materials	106	106
Field work	Plough	17	Rotary dig 11
	Disc harrow (2)	11	Disc Harrow (1) 6
	Drill	5	5
	Harrow	4	4
	Roll	4	4
	Spray (2)	5	5
	Fertiliser (2)	5	5
	Total field operation	51	40
Field work with fuel costs doubled	Total field operation	59	46
Field work with fuel costs quadrupled	Total field operations	75	58

Potential for power saving

Patterson's experiments at NIAE comparing different tillage techniques over six years (table IV)[2] have also shown the following

(i)Primary cultivation accounts for as much as 75% of the energy used up to the planting of the seed.

(ii)This energy varies by more than 2:1 between the primary tillage implements used.

Table IV Comparative energy inputs, excluding traction losses, to NIAE experimental plots, over six years, MJ/ha (Primary tillage only in parenthesis)

Soil & crop	Clay loam Winter wheat	Silty loam Winter wheat	Clay loam Spring barley
Traditional plough system	320 (245)	180 (118)	324 (307)
Shallow (100 mm) plough combined seedbed preparation and drill	187 (115)	108 (68)	203 (133)
Chisel plough (125 mm) twice, combined seedbed preparation and drill	286 (203)	194 (147)	308 (213)
Rotary digger (tines 200 mm, rotor 100 mm), combined seedbed preparation & drill	176 (117)	144 (88)	201 (156)
Direct drill, preceded by herbicide	38 (–)	43 (–)	54 (–)

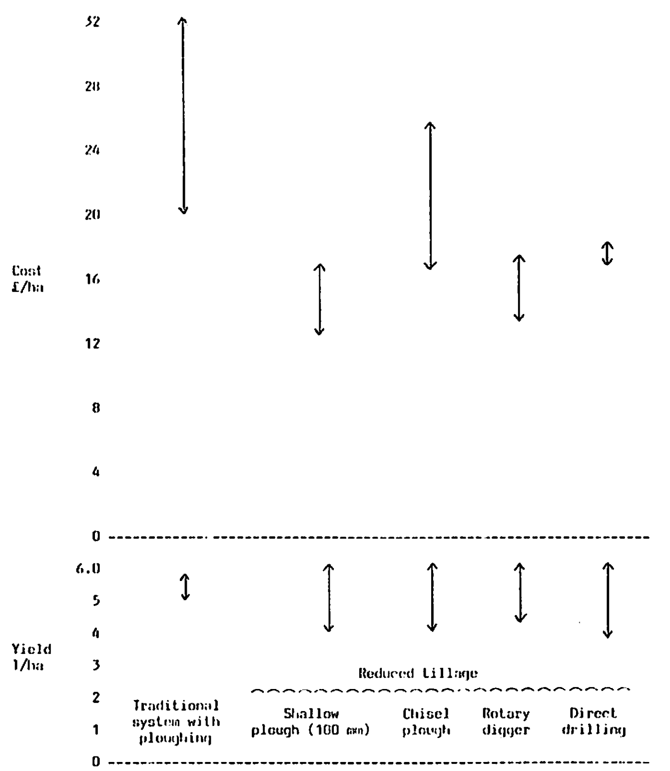


Fig 1 Tillage costs and yields from NIAE plot comparisons of reduced and traditional techniques.

(iii)A further energy reduction (5:1 compared to traditional plough tillage) is obtained by direct drill techniques.

(iv)In terms of tractor power a further reduction results from the employment of power take-off power with the rotary digger rather than tractive power with other implements.

(v)Energy use is approximately proportional to depth of work where comparison is possible (mouldboard ploughing).

(vi)At a similar depth of work, tined implements require less power than mouldboard implements. With a mouldboard plough the energy employed is divided, between soil shear, soil-metal friction and furrow inversion against gravity. According to Solovei[3] the frictional component can account for up to 80% of the energy in extreme circumstances. With less soil movement and inversion and less area to the soil-tool interface, the lower power needs of tined implements are easily explained.

For the future, energy requirement is probably most dependent on the ultimate reduction in depth of cultivation for cereals and for other crops. For cereals it may be concluded that under suitable conditions there is no need to till the soil below the depth of seed planting — say 40-50 mm. Suitable conditions here imply little rutting by wheels, adequate soil drainage and no critical weed infestation problems. Under such conditions it could thus be proposed that primary tillage could be carried out with an energy expenditure of 60 MJ/ha, and a complete system of primary and secondary tillage combined with planting with 120 MJ/ha. The comparative merits of separate secondary tillage and drilling or combining the processes in the same pass are largely the improved costs of the latter together with reduced wheel affects — in energy terms the difference is not significant.

The satisfactory operation of 40-50 mm tillage systems over a wide range of soil conditions may require considerable attention to wheel equipment, not only of the tractor or combine harvester, but also of trailers and perhaps balers and drills. Some work in progress at NIAE in which attempts have been made to preserve the tilth from one crop prior to harvest to the next planting by the use of only light vehicles with low tyre inflation pressures, shows promise of low energy inputs, but work is at an early stage.

For root crops, reduced energy cultivation is also at an early stage of application. Chamen has reported promising early trials with the rotary digger tilling for sugar beet (table V)[4], whilst tillage limited to the beet row has also been used successfully for the same crop[5]. In Holland, trials using a controlled traffic (bed) system of cultivation largely for vegetables, have reportedly shown that a tractor capable of pulling only three plough furrows in traditional cultivation, can pull up to five in the absence of wheel effects on the cultivation beds[6].

Table V Effect of tillage methods on the yield of sugar beet

Primary tillage method	*System Net rate of work ha/h*	*Mean yield of plots tonnes/ha*	*Degree of 'Fang' formation, % of roots in grade*			
			1	2	3	4
Mouldboard Plough, 215 mm depth	0.19	31.5 *	95	3	2	0
Rotary digger, rotor 100 mm, tines 200 mm depth	0.28	33.5 *	85	10	3	1
Rotary digger, rotor 150 mm, tines 250 mm depth	0.27	32.8 *	86	11	2	1

**Differences not significant*

Fang grade
1. *No 'fanging' – single tap root*
2. *One main root and one subsidiary*
3. *One main root and two subsidiaries*
4. *One main root and three subsidiaries*

Power requirement can thus clearly be reduced by avoidance of soil compaction. Another wasteful loss, already mentioned, is that due to friction between the tool and soil, and three developments in reducing this loss justify consideration. Low friction surface coatings such as Teflon may reduce draught force on a tool by up to 40%[7]. On a tine, Stafford has shown a 20% reduction to be possible[8]. Unfortunately, the wear resistance of suitable low friction materials is very poor — life in work appearing to be much less than steel — so that the practical application prospects are not good. Fluid lubrication of the interface with air or with liquids have both been investigaged. Draught reductions on mouldboards of 20% have been obtained by pumping large quantities of air through orifices over the mouldboard surface[9], although this requires fairly complex auxiliary equipment which also absorbs power. Of the liquid lubricants studied, work by Shafer *et al.* showed promise[10]. A polymer-water mix reduced the frictional coefficient of the interface by between one-third and two-thirds depending on the soil. From this they concluded that a 10-20% reduction in plough draught would be possible with the use of 600 litres/ha of the liquid — a scheme thought to be practicable on a field basis. Finally, the draught might be reduced by tool vibration — a reduction not entirely due to friction moderation but, depending on the vibration frequency employed, being related. At lower frequencies (10-30 Hz), draught may be reduced by as much as half but overall power is not likely to be significantly reduced, even though tractive efficiencies can be improved[11]. The phenomenon has also been briefly explored at ultrasonic frequencies where there was visual evidence that the vibration expressed water from the soil to provide lubrication[12]. Such frequencies of vibration of the tool are only produced very inefficiently however, and, apart from unattractive costs, power reduction overall is unlikely to be achieved.

Consideration next needs to be given to any other non-mechanical means which might be employed in tillage. These have been reviewed by Harral[13]. Explosive methods could include controlled conventional chemical explosions, or rapid release of steam from the soil by, say, microwave heating or by introducing super-heated steam. Pneumatic methods might include suction or high pressure to disrupt the soil structure. Soil erosion to produce a surface tilth could be achieved by water jets, by electric spark as in metal cutting or by a stream of particles. Slow break-up of soil structure by alternate heating and cooling or alternate wetting and drying is possible. Finally, the modification of soil structure by chemical means will probably be of the most significance in the future. However, none of the techniques listed appear to the author to be of sufficient economic value to have general application, at least in the next decade.

In Patterson's work, direct drilling has been shown to require only 20% of the energy of traditional cultivations[2]. However, direct drills as now built need to be heavy to provide coulter penetration, whilst coulter draughts are also relatively high considering all that is required is a 50-80 mm deep slit at 200 mm intervals. There must be some scope for seed placement directly into the untilled soil with still less power used. Dibbler techniques come to mind, whilst high velocity direct injection of seed has been proposed. The former would involve a high friction component at the soil dibbler surfaces and the latter probably large energy losses both in generating the sub-sonic velocities needed for injection and in the injection process. However, the complete avoidance of any tillage and of draught in the drilling process could reduce the vehicle (tractor) specification in a revolutionary fashion, hence moderating wheel effects on the soil and consequently easing the insertion process. Such developments clearly cannot be ignored, although would be long term ones and the application of such techniques would call for a particularly high standard of husbandry.

Accepting that with the inevitable slow spread of innovative techniques through the complete spectrum of farm types, tillage techniques relying on tractive forces from the tractor will persist in places for several decades, the improvement of the efficiency of this traction must continue. The tractive characteristics of existing tractors in the UK and the possible ways of improving efficiency have been well analysed and documented by others, particularly by Dwyer and Gee-Clough[14, 15]. Two wheel drive tractors fitted with the standard size of tyres offered at present operate throughout the season's tillage work with a mean tractive efficiency of only 60% — thus consuming additional power in wheelslip and rolling resistance equal to two-thirds of the power used at the drawbar. By various means likely to be exploited in the next one or two decades as fuel, and hence power costs, increase, this efficiency can potentially be increased to 75-85%. These means might include dual wheels and low inflation pressure tyres, higher operational speeds, higher speed and lighter-perhaps pneumatic — track equipment, or pto operation of the implement, with the latter most practicable with present day technology.

Economics of reduced power in cultivations

In this section the aims are threefold. Firstly, to outline the relationships between tillage method and cost so that the financial incentives on farmers to follow the various options may be assessed and hence the rate of uptake of these options predicted. Secondly, the form and particularly the size of power unit/vehicle will be largely determined by economic factors, although the author accepts that there are many factors such as taxation, prestige, tractor availability and design compromise for world-wide needs that are not quantifiable.

Patterson's perennial experiments with cereals provide a good basis for comparison of the costs of tillage techniques (table VI)[2]. Costs vary by typically £5-15/ha but with cereals valued at c£100/tonne, the tillage cost saving must not reduce yield by 0.1tonne/ha. With the exception of direct drilling under unfavourable conditions, there is no evidence of any crop yield reductions with the reduced tillage methods cited in the table. This conclusion is generally supported by trials carried out by many bodies in the UK[16]. Clearly, however, the economics are so relatively marginal that more sophisticated techniques must be used to examine them. One of the most important factors is the ability of the men and equipment employed to complete the tillage and sowing work in the time available in the season — so determining, for example, the proportion of the farm that can be planted in the autumn rather than left for the spring with potentially perhaps £40-50/ha less value of yield. To take all these factors into account a linear programme model has been developed and is described by Audsley *et al*[1]. This model has been used to predict the likely profit margins arising from the adoption of the various

Table VI Comparative costs of tillage treatments on NIAE experimental plots, over six years, £/ha

Soil & crop	*Clay loam Winter wheat*	*Silty loam Winter wheat*	*Clay loam Spring barley*
Traditional plough system	32	20	31.5
Shallow (100 mm) plough combined seedbed preparation & drill	16	12.5	16.5
Chisel plough (125 mm) twice, combined seedbed preparation & drill	23.5	16.5	26.5
Rotary digger (tines 200 mm, rotor 100 mm), combined seed-bed preparation & drill	17	13.5	16
Direct drill, preceded by herbicide	18	17	17.5

Table VII Farm gross margins predicted for some tillage methods with different cropping systems, £/ha

Tillage method	*All cereal heavy land*	*All cereal light land*	*Cereal/sugar beet heavy land*	*Cereal/potato heavy land*
Traditional (plough seedbed preparation, drill)	99	143	109	89
Chisel plough (twice), seedbed preparation, drill	111	146	119	101
Rotary dig, seedbed preparation, drill	121	151	129	107
Rotary dig. Combined seedbed preparation & drill	135	157	140	114
Direct drill preceded by herbicide spray	140	148	–*	–*

** Not considered in this crop rotation*

Table VIII Farm gross margins predicted when various tillage methods are operated with different power units, £/ha

*Tillage details**	*All cereal heavy land*	*All cereal light land*	*Cereal sugar beet heavy land*	*Cereal potato heavy land*
Traditional (plough, seedbed preparation, drill)				
56 kW tractor and implement	114	150	121	100
104 kW tractor & implement	115	148	120	89
Chisel plough (twice), seedbed preparation, drill				
56 kW tractor and implement	126	152	132	111
104 kW tractor & implement	126	151	130	99
Rotary dig. Combined seedbed preparation & drill				
56 kW tractor and implement	136	156	141	114
104 kW tractor & implement	138	157	139	109
56 kW tractor with trailer 104 kW tractor unit and implement	135	157	139	109

**Combined seedbed preparation and drilling practised in all cases*

techniques on both farms growing cereals only and those growing cereals and root crops. Although the computer programmes are designed to seek and employ the most suitable combinations of machines and men to maximise the gross profit margin, constraints may be applied to enable margins to be calculated for any combination (table VII). The programme takes account of yield reductions due to later sowing dates, including the yield penalty of spring sowing. As well as comparing different cultivation methods, it has been used to look at the economic effect of implement and power unit size (table VIII). The following conclusions may be drawn from these calculations:

(i) The choice of tillage method and hence implement for best profit depends a great deal on the crops grown and the type of soil on the farm (table VII and VIII).
(ii) Even where all the land on the hypothetical unit is devoted to cereals, direct drilling does not necessarily show the greatest profit (table VII).
(iii) Contract direct drilling does not increase profit[17].
(iv) The economic benefit of more shallow cultivation, as with the chisel plough or rotary digger, is clear (table VII). This benefit reaches an extreme with cultivation of the top 40-60 mm only of tilth as indicated in table IX.

Table IX Farm gross margins predicted for extreme minimal energy tillage systems, compared with existing methods, (400 ha, all cereal, heavy land), £/ha

Tillage details	
Traditional (plough, seedbed preparation, drill)	65–95
Rotary dig, combined seedbed preparation & drill	155
Tilth preservation system with broadcast seed	190–200
Non-draught direct drill with herbicide	180

(v) Further significant economic advantages accrue from reducing the number of tractor operations over the load by combining the seedbed preparation and drilling (table VII).
(vi) In general there appears to be no economic advantage in using larger (110 kW) tractors compared with 55 kW models (table VIII) although the influence of size on profits is not large.

To examine further the influence of tractor power and consequent implement size on the cost of tillage, a simulation model was developed by Zoz[18] and, in co-operation with NIAE, used with UK data to study the optimum tractor power, and speed and width of plough for an example farm with 80 ha of arable land all to be ploughed. This showed the most economic design of tractor to be one of 90 kW working at a speed of 7.5 km/h. The other conclusion was that the cost of work was, however, relatively insensitive to the size of the power unit with tractors from less than 40 kW to more than 160 kW working for within 5% of the lowest cost (fig 2). This model has been applied further at NIAE to study the influence of tractor characteristics on the least cost of chisel ploughing and of work with the rotary digger[19] (fig 3). In the former case the cost again is very insensitive to tractor characteristics. In the latter, speed is important, but power less so.

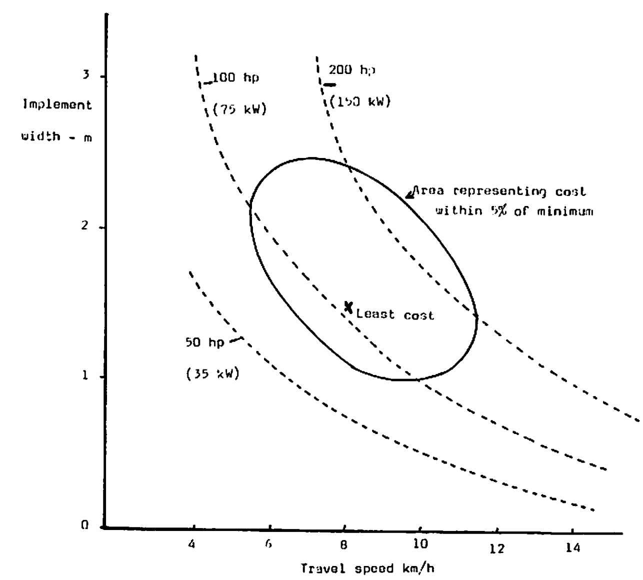
These conclusions must obviously be treated with much caution since they are based on fairly idealistic models without validation in practical situations. Nevertheless, they should enable the relative importance of the different possibilities to be better assessed.

Finally, the linear programme has been used to look at two extreme developments of present trends (table IX).

(a)The maximum preservation of tilth from one harvest to the next, using dual wheels on combine harvesters, 'terratyres' on grain trailers and a complete burn of straw and stubble. Within this tilth, seed is sown by broadcasting preceded and followed by a 'finger' tine implement requiring a draught of only 120 kg metre width (c20 kW at 8 km/h for a 4 m wide implement). A normal yield is assumed.

(b)Direct drilling after a herbicide treatment, using a revolutionary insertion method (perhaps dibbling) by which seed may be planted from a 50 kW vehicle plus mechanism, the whole

Fig 2 Optimum size and speed of tractor for most economic ploughing



costing £15,000 at a rate equal to twice today's direct drills, that is 3-4 ha/h.

In both cases the margin exceeds that of today's traditional and reduced cultivation methods. Although much research would need to be done still to make either of the above methods completely practical, the data does show that such research, if successful, would be well rewarded.

Other factors

The above considerations have not taken into account subsoil treatment and drainage, the possible large scale developments of precision planting for cereals, possibly encouraged by the breeding of hybrid 'bush' cereals, nor certain conceivable mechanisation systems such as mobile gantries, cable cultivation systems or driverless tractors.

The need for subsoil treatment for cereal growing when direct drilling or reduced culvitation are practised is not clear. If subsoiling is necessary every few years and tillage trends continue to require decreasing power so that farm tractor sizes decrease, the subsoiling as well as drainage are likely to be contractor tasks, thus not influencing farm tractor design.

'Precision' sowing of cereals has been shown in several trials to increase yield, typically by 5-15% and particularly for spring sown crops[20]. 'Precision' in this context has normally implied not only more regular spacing of the seeds along the row, but also greater uniformity of depth of sowing and, because of the press wheels incorporated on the drills most widely used, less clods but a greater firming of the soil in the region of the seeds. At this time the relative contributions of each of these factors to yield are not known. Neither is it clear to what extent the yield, and hence economic advantages, are attainable to autumn sown crops, where the economic potential is highest. If experiments show significant advantages, seed sowing mechanisms will be developed to achieve the appropriate 'precision' standards. However, the advantages of reduced power will surely mean that 'precision' sowing will be additional to rather than in place of reduced energy tillage.

Among the more fundamentally different mechanisation systems, controlled traffic arrangements may well be pursued with increased effort. A complete absence of wheel effects on the soil to be tilled can reduce the power required to till by up to 50%, and in a period of self-sufficiency the saving of energy may be more important than the cropping area lost to the permanent untilled wheel tracks. Vehicles may range from a pneumatic tyred, manually steered gantries spanning the crop bed, to automatically operating machines on concrete or even metal tracks, perhaps even hauled by cables. These types of development however call for revolutionary change in the whole equipment of the farm and, if they have advantages, the systems are unlikely to become common before the 1990's.

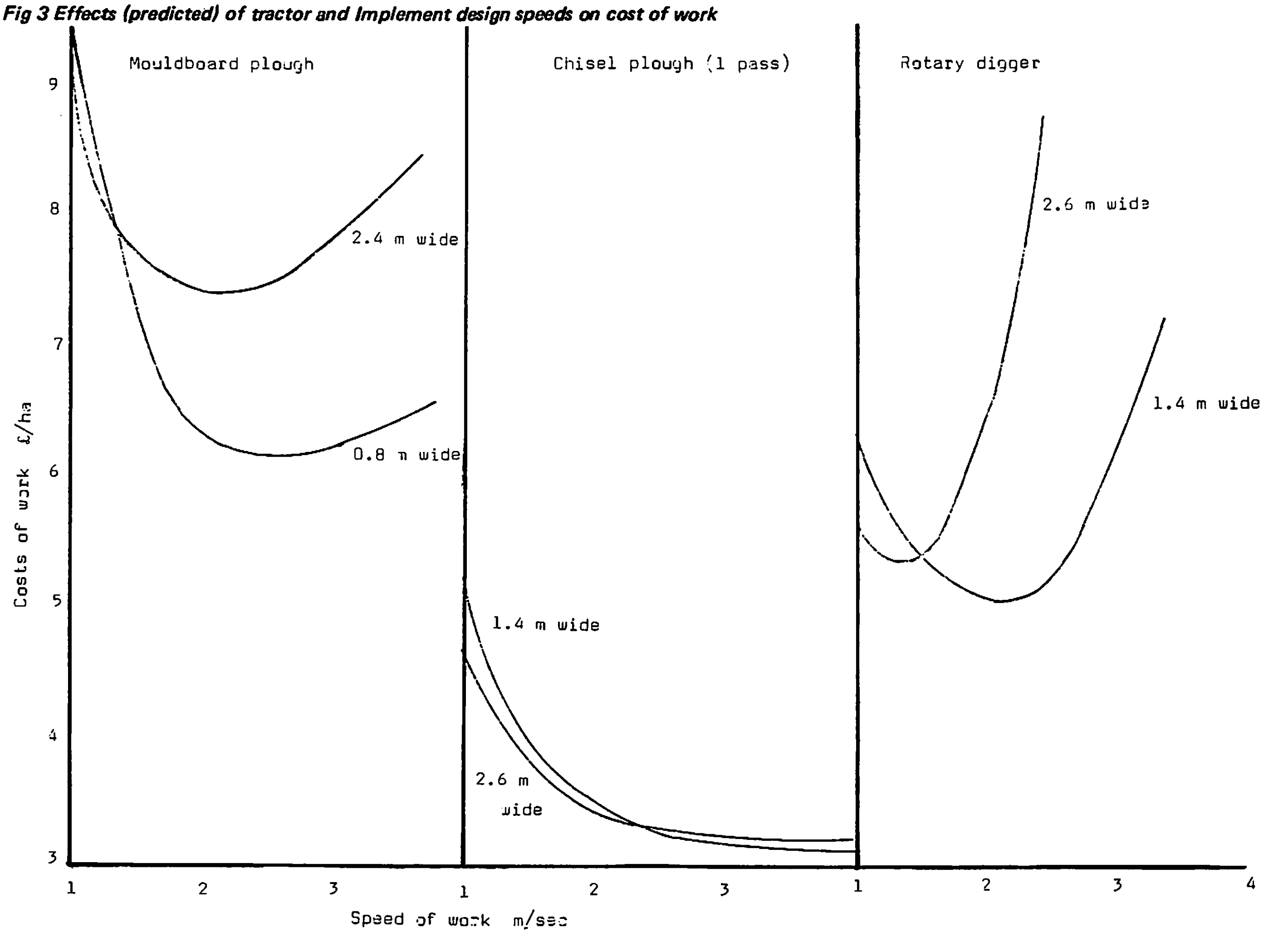
Finally, mention must be made of the experiments in progress at some research stations, which show yield benefit from tilling the soil below normal cultivation depth, particularly when fertilisers are mixed into the subsoil during this tillage process. For this purpose Wye College has developed its 'Double Digger'[21]. Inevitably this approach implies the use of considerable power — probably more than twice that of traditional cultivation — and its future is still unsure. It is not clear whether the additional energy at increasingly high costs will be paid for by extra yield. Also, it may be possible to obtain the extra yield, or most of it, by more conventional and less power-consuming, subsoil treatments.

Conclusions

Although it does not seem possible to predict cultivation power in the 1980's in terms of the total national energy expenditure because the unknown rate of uptake by farmers of the new methods available, the following predictions can be made on an individual farm basis.

(i) Reduced cultivation and direct seeding methods already fully explored by researchers and practised by farmers can reduce the energy input by up to 50% compared with traditional tillage techniques based on the mouldboard plough.
(ii) Techniques based on minimal soil disturbance, limited to the soil above seed level only and probably involving preservation of the tilth by the development or application of new wheel equipment, may reduce energy inputs by a further 50%.
(iii) Power for these lower energy tillage practises of the future is likely to be most economically produced by 50-80 kW tractors. These should be fitted with tyres able to carry a weight

Fig 3 Effects (predicted) of tractor and implement design speeds on cost of work



corresponding to 100 kg/kW on the driven wheels at an inflation pressure of not more than 80 kpa.

(iv) The use of pto powered tillage equipment leads to more efficient use of tractor power, improvements may be as much as 50% when tillage is at 100-200 mm as with the rotary digger, It has not yet been shown that the same advantage can be obtained at 50-100 mm depth; but the potential should be explored.

(v) There would appear to be scope for the development of seed insertion equipment which does not require tractor draught. Although the mechanism for insertion may be more complex than that of traditional drills, its use would enable considerable simplification, cost saving and fuel economy of the tractor,

(vi) The importance of more precise seed placement has not yet been established. Neither has the need for subsoil treatment as a routibe process in contrast with its use to rectify wheeling or implement 'panning' effects.

(vii) Some more revolutionary developments, particularly involving controlled traffic of the machinery, are suggested, but are unlikely to be generally applied during the 1980's.

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How can the engineering industry meet these requirements

J R O'Callaghan

Summary

THE challenge facing the designer of tillage equipment in the 80's is how to match a more powerful range of tractors with equipment which is able to reduce farmers' production costs. Crops are our most valuable solar collectors; the agricultural engineering industry is required to increase the effectiveness of the energy input at the planting of the crop, thereby improving the overall energy ratio of the farming system.

The industry has the capacity to produce a new generation of cultivation equipment but it needs support, particularly from its customers. Farmers and crop husbandry specialists can help by indicating the direction in which they wish to see cultivation practices developing and by specifying their objectives.

The challenge facing the designer of tillage equipment in the 80's is how to match a more powerful range of tractors with equipment which is able to reduce farmers' production costs. Obviously it is not an easy challenge to meet because, as the drawbar pull of tractors increases, the forces on the implement trailed behind them also gets bigger. The trend has been for implements to get wider, heavier and more expensive.

The traditional response of the implement designer to an increase in the power rating of tractors has been either to modify a conventional piece of tillage equipment to absorb most of the increase in power through an increase in width and perhaps a small amount of extra power through a slight increase in forward speed or to dream of taking most of the engine power through the pto. Further progress along these routes is unlikely to be spectacular because

— an increase in width of conventional ploughs and cultivators carries penalties of weight and cost as well as loss of control of working depth. Field contours are uneven with the result that as the working width of an implement increases, it needs to work deeper in order to avoid missing some patches altogether. Greater depth of working increases the average draught of the implement and hence the overall power consumption.

— increase in speed is limited in some cases by the performance of the implement, eg mouldboard ploughs, and ultimately by the tolerance of tractor-drivers to vibration.

— pto driven tillage implements are an attractive idea and a logical extension of the way in which power transmission to harvesting machinery evolved. Unfortunately, despite intensive development, the effectiveness with which pto driven equipment converts energy into tilth has remained low. Perhaps through the clearer understanding which is emerging of how a tilth is formed by implement-soil interaction, the effectiveness may be improved, at least under conditions of shallow cultivation. Problems of weed control and maintenance of depth of working for a shallow bite over a wide machine would still remain.

The cultivation problem

The specification of what is required in cultivation equipment is not well defined by farmers or crop husbandry specialists for the engineering industry. Cultivation is one of the processes in the management of the soil to create a suitable environment for the production of a crop from germination to harvest, within the constraints of what is feasible economically. It is well to remind ourselves that the needs of the crop change with different stages of growth, that soil is a complex medium and that environment cannot be characterised by a single factor.

At sowing of the seed, cultivation is expected to provide the right conditions for germination and for ensuring that both emergence and establishment of a root system will have taken place before the energy reserves of the seed are exhausted. When the plant is established, there is a period of very rapid growth when an adequate supply of water and nutrients is important. Cultivation may also be expected to help in the disposal of crop residues, in the control of weeds, in mixing fertilisers into the soil and in preparing a suitable terrain for harvesting machinery.

It should be emphasised that the soil environment of the plant is a balance between such factors as moisture, nutrients, temperature, aeration, soil strength and that many of these factors are more dependent on weather and soil type than on the method of cultivation.

The objective of the farmer is to optimise the environment for plant growth by manipulating the soil factors and controlling competition with the plant from weeds and pests. Agricultural research has given us a very good understanding of the chemical/nutrient component of the environment. The problem for the agricultural machinery industry is to find ways of influencing and controlling the physical/weed environment of the plant through the use of energy inputs in the form of cultivation.

Assumptions

(i) The cereal crop offers the main market for cultivation machinery in Britain. There will be a gradual increase from present levels in the total area under cereals, with a large switch from Spring to Winter cereals.

(ii) The optimum sowing period for winter cereals is during the period mid-September to mid-October, and for spring cereals, early to mid-March.

(iii) Control of soil environment has both a long-term and an annual component. One result of the expansion of cereal growing is an awareness of the need to modify some soils to get better control of soil water by drainage and deeper rooting by sub-soiling.

(iv) The presence/absence of crop residues on the soil surface is of crucial importance in the selection of tillage equipment. Burning straw helps in the control of disease and weeds as well as reducing the risk of blockages in machines. When straw remains on the surface the merits of inversion as a means of disposal need to be considered.

The cost of cultivation

The total cost of cultivation may be summarised under four headings:—

(i) *Fixed costs* which reflect the capital cost of the machine and on a per hectare basis are a function of annual utilisation.

(ii) *Variable costs* which are directly associated with the use of a cultivator and include the costs attributable to the tractor.

(iii) *Labour costs* which are inversely proportional to the work rate of the cultivator.

(iv) *Transfer costs* which take account of the cost/benefit effects on the cultivation process on the other parts of the crop production cycle. Transfer costs are difficult to assess but should make allowance for the effectiveness of a cultivation in controlling weeds, the contribution of a high work rate to the potential gains in yield through timeliness of sowing, the reliability of the system over a number of years etc.

Professor J R O'Callaghan is from University of Newcastle upon Tyne

Paper presented at the Tillage Equipment Design and Power Requirement in the '80's Conference at the National Agricultural Centre 9 October 1979.

Whatever the absolute values of the different components of costs, it is clear that a high work rate has a beneficial effect on (ii), (iii) and (iv) while (i) should be as small as possible! The outline of the cultivator suggested by the cost equation is one travelling as fast as the tractor-driver thinks fit, wide enough to match the power of the tractor and only disturbing the 'minimum' amount of soil necessary to optimise the physical environment for the seed/plant.

Three trends in cultivation can be distinguished with the possibility that the distinctive features which separate them will become more pronounced through the development of machinery:—

(i) Direct drilling of cereals has potentially the highest work rate. The system appears to its best advantage with Winter cereals where the time between harvest and planting is short, However, direct drilling works best on level, well drained loam soils free of surface trash. The engineering development problems of the direct drill are those of improving performance on loam soils and of widening the range of soils on which it will give an acceptable performance.

Better performance on loam soils means higher work rates, better control of seed spacing and reduction in the cost of manufacture. All of this resolves to the specification and design of a satisfactory seed placement mechanism that will give rapid germination and establishment of a vigorous stand of singly spaced plants. Uniform depth of placement and an adequate supply of moisture are more important than the horizontal spacing between the seeds. Further research and development on placement mechanisms for cereals is required, but for mechanisms that will operate under field conditions at speeds of 10 km/hour.

The research which is in progress on furrow openers will widen the range of conditions under which direct drilling is feasible. Much of the work is aimed at improving the capability of drills in dealing with trash. Another, but more long term way, of increasing the area that may be direct drilled is to improve the movement of water and roots through the soil by drainage and sub-soiling.

(ii) Inversion of the surface layer is such a well established part of the cultivation process in temperate climates that engineers may be forgiven for accepting the need for the operation but for questioning the thickness of the layer. Is it possible to separate the processes carried out simultaneously by the mouldboard plough — decrease in the bulk density of the top soil, burying of surface trash, removal of wheel ruts, control of annual weeds, improvement of surface drainage? Some of the operations need to be carried out annually, others are part of the long term improvement of the soil environment.

A cheap, wide, shallow plough with a high work rate which could bury surface trash and weeds without the high energy consumption of the conventional mouldboard plough would be assured of a market by the cereal farmers. The problem for the designer is to devise a plough working at 5 cm depth which will follow the terrain burying trash and be easy to manufacture.

(iii) Long term improvement of seed beds is part of the key to raising yields on either direct or conventional drilled crops. Better drainage improves the chances of sowing Winter cereals and of earlier growth in the Spring. Sub-soiling encourages deeper rooting and increases the amount of moisture available to the plant in the late Spring and early Summer. Unfortunately drainage and sub-soiling are slow, expensive operations whose value is more easily demonstrated under extreme conditions than in normal circumstances. Further husbandry trials are needed to establish the value of drainage and sub-soiling under various soil conditions while engineers think of new machines to produce the effects with less power and at a lower cost.

Conclusion

Crops are our most valuable solar collectors. What is required of the agricultural engineering industry is to increase the effectiveness of the energy input at the planting of the crop, so that the overall energy ratio of the farming system is improved. The industry must improve cultivation machinery by improving both the function of the machines and their fabrication. Functional improvements have been discussed for three categories of equipment — direct drills, soil inverters and long term improvers. In every category there is need for some research to strengthen basic understanding, for considerable innovations to get new machines which are a better match for bigger and more powerful tractors and for better designs that are cheaper to manufacture.

The industry has the capacity to produce a new generation of cultivation equipment but it needs support particularly from its customers. Farmers and crop husbandry specialists can help by indicating the direction in which they wish to see cultivation practices develop and by specifying as clearly as possible their objectives. However, development of cultivation equipment is very much a partnership between manufacturers and farmers assisted by research and development specialists. If British farmers are prepared to buy British equipment and British manufacturers are prepared to stand behind their engineering staff in development and production, the future of both the farming and manufacturing industry will be both secure and exciting.

INSTITUTION OF AGRICULTURAL ENGINEERS

1980 Conference Programme

Spring National

Date:	**25 March 1980.**
Venue:	University of Newcastle-upon-Tyne. (In association with Northern Branch and supported by the Institution of Electrical Engineers)
Subject:	**Electronics in Agriculture.**

Annual

Date:	**13 May 1980.**
Venue:	Allesley Hotel, Conventry.
Subject:	**Engineering for Agriculture in the 21st Century. The Annual General Meeting, Presidential Address and Annual Luncheon of the Institution will also take place on this date.**

Autumn National

Date:	
Venue:	National College of Agricultural Engineering, Silsoe, Bedford. (In association with South East Midlands Branch)
Subject:	**Agricultural Machinery Manufacture in Developing Countries.**

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1981 Conference Programme

Spring National

Date:	**17 March 1981.**
Venue:	Wye College, Kent. (In association with London/Kent Branch).
Subject:	**Engineering in Horticulture.**

Annual

Date:	**12 May 1981.**
Venue:	National Agricultural Centre, Stoneleigh, Kenilworth.
Subject:	**Engineering for Beef Production.**

Autumn National

Date:	**13 October 1981.**
Venue:	To be decided. (In association with North Western Branch).
Subject:	**Engineering for Intensive Vegetable Crop Production.**
All enquiries to:	Mrs Edwina J Holden, Conference Secretary, Institution of Agricultural Engineers, West End Road, Silsoe, Bedford MK45 4DU.

Tillage equipment design and power requirement in the 80's

Edited summary of discussion

Mr Rogers *(Pettit)* asked what cultivation systems would be used if there were more industrial use of straw and less straw burning?

Dr Bryan Davies did not think there would be more use of straw for industrial purposes. If there were, he mentioned two systems, one which makes use of equipment that parts the straw and the second recently seen in Germany, consisting of a front mounted flail chopper which blows the material to the rear and is fitted with a cultivation and seeding device behind the tractor.

Dr R Cannell did not consider that the premise of more straw utilisation for industrial purposes was correct.

W R Catt *(ADAS)* said that, whether or not the premise that straw could be utilised for manufacturing was correct, farmers could do with a machine that would give a safe and effective burn without using a great deal of fossil fuel.

Mr Griffiths *(farmer)* described his method of producing a vortex of wind some 50 ft high — it took him 3½ min to burn a field of 30 acres. He intends to publish his information shortly.

T C D Manby *(NIAE)* had seen machines in the USA using the same principle as those used for burning tar off the roads. However, although they were based on good engineering principles, their cost was high and despite good air flows, it was found difficult to burn damp straw, particularly at reasonable speed, and without a fossil fuel input.

Dr Cannell said that work at Letcombe by Dr Lynch had shown that harmful phyto-toxins are only produced in the first three or four weeks after straw incorporation, thus early mixing in of straw by shallow cultivations could be the answer to some of the problems. This certainly seemed to work in France where harvest was a little earlier.

Mr G McPherson *(Big Farm Management)* suggested incorporation of straw meant ploughing; perhaps we would see a return to this.

Mr Scott said that straw burning may become illegal and in any case there is always some straw to be dealt with. He therefore considered that it would be important not to move away from conventional systems and mentioned the disc plough as a means of inverting soil and trash.

G E Tapp *(County Commercial Cars)*, asked what type of tractors Mr Scott used and whether, when he opted for higher power, he carried out cultivations faster or at a greater drawbar pull.

Mr David Scott replied that he had opted for 4 W D, equal wheels, pivot steer with eight wheels on each tractor; his implements had become wider while his forward speeds had been maintained. Labour requirement had been reduced as a result of this.

T C D Manby took up Mr Scott's point about testing. There were always problems with expressing results, particularly of cultivation implements. Could the speakers comment on this problem?

Dr D B Davies said that ADAS had attempted this in the past ten years; measurements had included clod size distribution, strength of soil below the seedbed, water behaviour and the crop itself as an indicator. Evaluation along these lines could possibly be used.

Prof. R D Bell *(NIAE)* commented that this was a long process while Dr Cannell said that cereals were very insensitive as an indicator to these sort of changes.

Mr Scott replied that as first off it would be useful to have just a basic testing of power units and the more straightforward implements.

Prof Bell asked Mr Scott what he found lacking at present. Mr Scott felt that the format was too complicated and often too much detail was given to be able to form a clear picture.

Mr Metcalfe *(ADAS)* said that it was not possible to decide on the most suitable tractor from the OECD test reports. It was necessary to relate the particular implement in your situation on the farm to help select the tractor.

Mr P Lambert *(Pettit)* wondered whether the British manufacturers would respond to new techniques. There had been reformation of systems in the UK but was this reformation mirrored elsewhere in the world.

Bob Cannell said that in certain parts of the USA there had been a tremendous interest in zero tillage particularly for maize and soya beans. One of the reasons for this was erosion control. In general there had been less interest in zero tillage for cereals but in Alberta direct drilling was being used for continuous cereal growing.

In West Germany farms were much smaller and mixed cropping was practised, so there was little reduced tillage.

In France there was interest in simplified cultivation systems.

In Brazil and Australia — there were great opportunities for zero tillage.

G Spoor *(NCAE)* commented that speakers were working on the assumption that cultivation implements were the major component in a tillage system. However, many wheels pass, between cultivations; in many cases the wheel could be regarded as the main implement. Dr Davies, he said, had mentioned lack of wheelings and the fact that on many occasions no cultivation at all was necessary. In many instances the final result of cultivations was to return to the status quo. Surely our aim for the 80's should be a more efficient use of cultivation implements together with some sort of controlled traffic regime.

Dr. Davis added that combine harvester wheels were particularly bad at causing compaction and any work on this aspect would be gratefully received by everyone.

Dr Cannell supported Mr Spoor's call for controlled traffic and on the basis of work being done, this would appear quite feasible. Dr Ellis, working on this aspect, had already found new problems however with weed flora in wheelings being different from that in the field as a whole.

Mr Scott said that he reduced some of his wheelings by using a bridge link to combine secondary cultivation and drilling.

Peter Wakeford *(Farm Electric Centre)* asked if there was the possibility of pursuing hovercraft principles?

John Matthews thought that this would not be feasible but felt that the use of terratyres on tractors would go far enough in theory providing it was economic.

Mr Austin *(farmer)* asked the speakers how often subsoiling should be done; in his case he had drained and moled with seemingly little effect.

Prof. J O'Callaghan thought that once in six or seven years should be sufficient.

Dr D B Davies, having established that Mr Austin used backfill, suggested that a profile should be dug to look at the problem.

Mr Griffiths *(previously Howard now farmer)* said that he was following Stephen Bond's recommendations and replacing sub-soiling by direct drilling. He had found that his structure was improving every year the lower drainage being satisfactory; direct drilling promotes worm activity which allows water to drain away.

R J Nickerson *(farmer)* said that superseding the wheel was the real problem; so much damage was caused by the amount of weight needed to make the wheel efficient. A 75 hp crawler tractor, he said, could pull the equivalent of a 100 hp wheeled tractor with less damage to the land.

J Matthews confirmed the comparison between a track and a tyre, although he thought 90 hp would be the equivalent. Metallurgy, he said, had improved the cost of running tracked vehicles, but this was very soil dependent. There was at present work being done on more sophisticated tracks because the present metal type is very inflexible. Comparison between tractors is often argued, said Mr. Matthews, but much of the difference in performance is in the skill of the operator.

C V Brutey *(NFU)* considered that Prof O'Callaghan had side-swiped farmers by suggesting that farmers should stand by the British manufacturers. As farmers cannot obtain British machinery it was more that the British manufacturer should stand by the farmer.

Prof. Bell said that it was important to have co-operation by all parties. He asked John Fox for his comments.

Mr Fox *(Bomford & Evershed)* felt that many overseas manufacturers have a large market in their country which provides them with a very good base for expanding into our market. This was particularly so in the cultivation sphere and this means that the overseas manufacturer can sell machinery cheaper than UK manufacturers. He said that his company was doing everything it could to improve this situation and was looking at ways of doing this through the Department of Industry.

A F Pemberton *(farmer)* was delighted that the weather had been mentioned; this was a most useful tool if it worked for you. He went on to say that maximum width of implements had been mentioned but there had been no word about implements in tandem.

Mr Matthews replied that some of his work quoted Patterson's experiments where implements had been used in tandem. It was better obviously to use the weather if possible, but where this could not be done, then it had proved very economic to use implements in tandem. It was likely that this practice would expand with fore and aft mounting of machines.

Prof O'Callaghan did not like the idea of a circus of implements; in a way this was admitting defeat: better a single implement because of a lower cost. The weather was the best way of achieving the necessary results.

Mr Brutey observed that there was one factor missing regarding width of implements. Currently there was a tightening up by the police against the movement of wide implements.

Regarding coupling of machines this was done many years ago with Fiat crawlers and a major advantage was the merit of flexibility of grouping of implements.

Mr John Matthews confirmed this view. It was important to have the right implement for the particular conditions and a bridging link provided the means of having this flexibility.

Dr Cannell commented that people often ask what is the minimum feasible depth of cultivation. In this context, is any work being done on contour following?

Dr Blight replied that certainly more attention should be paid to this subject. SIAE had experienced difficulty with an 8 furrow shallow plough, particularly where this had been used on hill farms. . The problem was also accentuated by the fact that shallow cultivations are always attended by greater widths of implement.

Mr Jeffes *(Stroud)* asked if powered discs would be suitable for operation on a cereal stubble.

Mr Matthews spoke of the work in the USA on a prototype powered disc harrow and was surprised that it had not progressed further in the drier conditions prevailing in the USA. Powered discs were, however, not so good in wet conditions because of blockage problems. Mr. Jeffes said that he had tried powered discs and they did not block in wet conditions.

Mr Horstine Farmery remembered that his father used to spread seed and fertiliser in front of the shallow plough. As he felt it should be relatively easy to make a plough beam follow ground contours, he asked for comments by the panel.

Professor O'Callaghan thought that the advantage of the operation described was the small cost of doing it, but one must be very careful not to depress crop yield. It was important to get seeds into a seed bed where there is high biological activity as high growth rates help enormously. The seedbed in such a situation may not be very suitable; it would be too dry and not sufficiently compact.

Dr Blight said that he had discussed with Mr Holmes of the Scottish College the question of broadcasting. He said its success depended on the climate and with the high rainfall in the East of Scotland this was a suitable technique. It was important however to put on about 5% more seed than normal.

SIAE had investigated broadcasting of seed and the results obtained had been as good as normal drilling.

Regarding depth of sowing Russian work had shown that seed would get to the surface from a depth of 20 cm.

Dr Cannell noted that Percival had quoted maximum depths of 10 cm for emergence of seed with 4-5 cm being most consistent.

Mr Tapp *(County Commercial Cars)* said that there was a wide range of tyres from which to choose, but all too often too high tyre pressures were being used. He felt that we should look closely at our tyre equipment and also consider the important of radial tyres.

Comparing wheeled and tracked vehicles, it would appear from some Silsoe results that no difference in performance could be measured.

J Matthews replied that the results he had quoted had been the average of 2-wheel and 4-wheel drive tractors.

J S Rymer *(farmer)* commented that a lot had been said about over-compacting and suggested there was as much loss of yield due to under compaction. On his farm where pea viners were used, his remedial action for compacted ground was ploughing, but this he followed with a furrow press to re-consolidate the soil and get rid of air pockets. Mr. Matthews said that there was a general tendency to say that we want light vehicles. Perhaps we have deplored heavy vehicles too much — we can achieve ground pressure of 2 p.s.i. above the tyre pressure. Our evidence suggests ballasting of 120-130 lb hp with a tyre pressure of about 14 lbf/in^2. He suggested that wheel slip reduction would more than compensate for the greater weight.

Mr Stanely *(farmer)* asked if all speakers regarded a good burn as a prerequisite for what they said.

Dr Cannell replied that there was evidence from EHFs to show a disadvantage in not getting rid of straw when carrying out shallow cultivation.

Mr Bee *(Drayton E H F)* said that it was not absolutely necessary to burn stubble although it was ideal in many ways. If you can't burn he said, it was best to get in as early as possible to incorporate the straw and get maximum weathering, ideally six weeks between crops. He had been quite happy with his system of shallow tining over the past ten years.

Mr Stanley came back saying that it was difficult to get rid of all the straw in this way and he observed baling it meant more wheels on the land which was not advocated.

Mr Griffiths commented that only 40% of N_2 put on the land gets to the plant. Is work being done on the application of fertilisers through the leaf, rather than through the soil, e.g. will it be possible to do this through a micro spray and reduce cost of fertiliser.

Dr Davies said that there was little investigation into foliar feeding. This technique was quite possible but it may not greatly reduce loss of N since it is passed into the soil from the root. A lot of N_2 is then lost from the soil by mineralisation of organic matter.

There was some potential for saving N_2 by using direct drilling techniques since there was less autumn N_2 mineralisation and thus less leaching over winter. On sandy soils in Denmark one could retain an extra 40 kg/ha of N_2 by direct drilling. A cover crop also helped in this respect.

Mr Beeny *(Halcro, ULG Ltd)* asked if any successful work had been done on irrigation techniques for pre-saturating the notoriously heavy clays, such as found in the Sudan or East Africa, before cultivation.

Prof O'Callaghan said that the use of tines would in these conditions promote a great deal of fragmentation of the soil, but the power requirement would be very high. It seemed that the only solution would be to change the moisture content. He said there was a close relation between high power, moisture content and fragmentation.

D N Scott *(Contractor, Doncaster)* asked Mr Matthews if it was really the case that ground pressure was 2 lbf/in^2 greater than inflation pressure; he thought that in many cases it wasn't as close as this. John Matthews replied that he thought it was, but it did depend to a large extent at what depth you looked at it. If a narrow and wide tyre having the same inflation pressure were compared, then pressure at the surface would be the same. If, however, you looked below the surface, then the inverted pyramid effect came in, and the wider tyre would be found to have transmitted compaction to a greater depth. This type of compaction was of course more difficult to eradicate and thus low inflation pressures should be aimed at if possible. Mr Matthews continued to say that he hoped he hadn't given the impression that we should accept tyres as they are today, further work could be done on the low inflation pressure aspect.

Turbocharging to reduce tractor power loss at high altitudes

B G Sims, J E Ashburner and L Rodriguez

Summary

TRACTOR power loss with altitude is a serious problem in the Andean Sierra of South America. One way of reducing the power loss is by turbocharging the engine and this study measured the power output of a modern diesel engined tractor both naturally aspirated and turbocharged up to an altitude of 3850 m above sea level.

It was found that power loss could be eliminated up to 2325 m and thereafter the turbocharged engine gave an average of 32.6% more power than the naturally aspirated version.

The cost of turbocharging a smaller engine as opposed to using a larger naturally aspirated one is much less, although there are other differences (such as weight and hydraulic system capacity) which may be of overriding importance.

Introduction

The loss of tractor engine power while working at altitudes has been measured in East Africa (Manby 1961). More recently the Agricultural Engineering Department of INIAP, The Ecuadorean National Agricultural Research Institute has studied tractor power loss at altitudes of up to 3700 m in the Andean Sierra of Ecuador (Sims and Vera 1978). The results of that work showed that a highly rated diesel tractor engine with a fuel-to-air ratio in the region of 60 $mm^3/1$ will begin to smoke and lose power as soon as barometric pressure is reduced. Increase in altitude is the main cause of reduction in barometric pressure, but increases in air temperature have a similar, though much lesser, effect. When a diesel tractor engine starts to lose power as a result of a lack of oxygen (caused by an increase in altitude) then it is found to do so at a rate of about one per cent for each 100 m increase above sea level. To overcome this power loss, which can cause problems when trying to match tractors to implements for high altitude work, there are two possibilities:

- a larger engined tractor can be selected and derated (ie its fuelling can be reduced so that it does not eject black smoke under load) or:
  the air supply to the engine can be increased by turbocharging.

Not surprisingly the latter alternative would be the cheaper but the actual difference in cost will depend on the degree to which turbocharging can compensate for power loss in a particular situation. For example if a 60 kW tractor produces only 40 kW at 3300 m above sea level and this could also be achieved by a turbocharged 45 kW tractor; then we must compare the cost of a turbocharger with the difference in cost between a 45 and 60 kW tractor. There is very little quantitative information on the degree to which turbocharging can compensate for power loss with altitude so the Agricultural Engineering Department of INIAP decided to measure the loss experienced by a modern diesel tractor with and without a turbocharger. We measured maximum powers at altitudes ranging from approximately 1500 to 3800 m above sea level which covers all the agricultural areas of the Ecuadorean Sierra.

Power measurement

For the study we used a Massey Ferguson 185 tractor whose engine was loaded by connecting a hydraulic dynamometer (M and W Gear model P-400B) to the power take-off shaft. The torque and speed of the shaft were measured by a strain gauge torque transducer (Saunders-Roe type 2 Mk 4) and an optical tachometer.

B G Sims BSc MSc DTA MIAgrE TEng (CEI), Overseas Division, National Institute of Agricultural Engineering.
J E Ashburner PHD MA MIAgrE CEng MIMechE and L Rodriguez C Ingeniero Agronomo, Institute Nacional de Investigaciónes Agropecuarias, Quito, Ecuador.

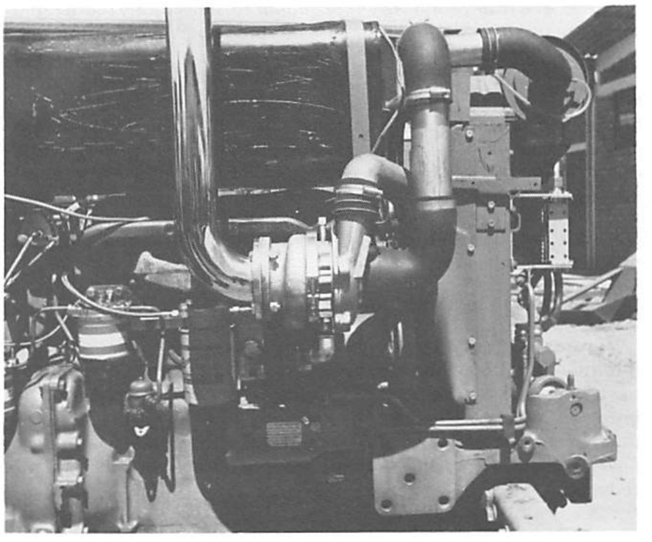


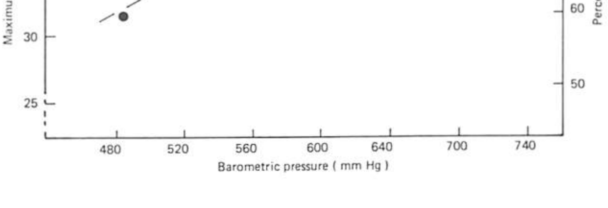
Fig 1 Massey-Ferguson 185 tractor fitted with Opico turbocharger bit

(British Hovercraft Corporation type NP1). A British Hovercraft Corporation TM30 indicator gave a reading of torque, speed and power. The transducers and indicator were calibrated in the laboratory, and the conversion factors calculated, before the tractor tests. The first tests (from 3750 to 1525 m above sea level) were of the tractor without turbocharger. The turbocharger (supplied as a conversion kit by Opico UK) was then fitted (fig 1) and the tests repeated over a slightly increased altitude range 1320 to 3850 m above sea level). At each test site the engine was run until it was warm and then, with the governor control completely open, the hydraulic dynamometer was adjusted until maximum power was indicated. The test was repeated three times at each site. To take into account the subsidiary effect of air temperature, the standard DIN (1957) method for temperature correction was applied to the maximum power values.

Results

The results, which were subjected to regression analyses, are summarised graphically in fig 2. The unturbocharged engine shows the typical practically linear relationship between power and barometric pressure. Power loss was 10.9 kW for a fall in barometric pressure from 635.7 mmHg (1525m) to 484.1 mmHg

Fig 2. The effect of barometric pressure on maximum pto power Engine with and without turbocharger



(3750 m). This corresponds to a 1.16% power loss for each increase of 100 m above sea level and the result is practically the same as that obtained for the Massey Ferguson 135 (Sims and Vera *op cit*). The power curve of the turbocharged engine is, however, totally different. A reduction in barometric pressure to 575 mmHg (2325 m) has practically no effect on the maximum power developed. This is because air supply is not limiting, as excess is being supplied by the turbocharger and so all the fuel injected into the cylinders can be burnt. Further reduction in barometric pressure resulted in loss of power at a rate which was very similar to, but slightly more rapid then, the unturbocharged engine. The rate of power loss from 575 mmHg (2325m) to 478.1 mmHg (3850 m) corresponds to a loss of 1.7% per 100 m increase above sea level. Over this range of barometric pressure the maximum power developed by the turbocharged engine is always more than that developed by the unturbocharged version. The percentage increase in power in this range varies slightly having a range of 31.0% to 34.2% with an average of 32.6%.

It can be seen that the extrapolated curves do not coincide precisely.

This is due to experimental error.

We did not alter the rate of fuelling of the engine as it was not our intention to increase the sea level power of the tractor. Our aim was to compensate for the power loss with increase in altitude and the graph shows clearly that this can be done with no power loss down to a barometric pressure of 575 mmHg (2325 m) after which the power loss of the naturally aspirated engine can be substantially reduced.

Implications

The 32.6% increase in maximum pto power due to turbocharging means that a tractor like the Massey Ferguson 185 (which has a sea level maximum pto power of 52.6 kW specified by the manufacturers) is able, in the Ecuadorian Sierra above 2325 m, to develop the power of a naturally aspirated engine that would produce about 70 kW at sea level. We did a survey of tractor importers in Ecuador in November 1978 and we found that the average difference in price between tractors of about 52 and 70 kW was £5750. The turbocharger kit costs £650 and even if this were to be doubled before it was fitted in Ecuador, the price difference would still be considerable. It is, perhaps, a little unfair to try to compare directly a relatively small turbocharged tractor with a naturally aspirated larger model. The advantages and disadvantages of turbocharging have been discussed elsewhere (Sims and Vera *op cit*) but it is worth emphasising that a little more care is needed on the part of tractor drivers. They must allow the engine to idle on starting and before stopping to make sure that the turbocharger shaft bearings are always lubricated. Oil and air filtration must also be excellent at all times. We recognise that there are, of course, usually other differences between tractors of differing sea level outputs. Among these differences, which may be of overriding importance, are tractor weight and hydraulic system capacity.

Acknowledgements

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The ride and handling of tractor and trailer combinations

D A Crolla

Summary

THIS paper describes theoretical research into the dynamic behaviour of tractor and trailer combinations. Two simplified theoretical models, dealing with motions in the vertical and lateral planes, were devised to investigate ride and handling behaviour respectively. The analysis shows that tractor ride vibration is modified significantly by the addition of a trailer; operator vibration levels increasing particularly in the pitch and longitudinal directions. The analysis of handling demonstrated the potential lateral instability of the combination both at high speeds and during braking.

Although both ride and handling qualities can be improved slightly by geometrical variations, such as hitch position, it is concluded that greater scope for improvement lies in changing the configuration substantially. Therefore, a speculative suggestion for an improved agricultural transport vehicle, which resembles an off-road version of an articulated road vehicle, is proposed and its ride and handling characteristics discussed.

Introduction

The problem of materials handling and transport on the farm has received considerable attention recently[1]. At NIAE, possible configurations for the next generation of farm transport vehicle have been analysed[2]. This vehicle, whatever form it takes, will have to compete with the present tractor and trailer combination to be successful, so it is of considerable importance to analyse and define the dynamic limitations of tractor and trailer combinations. The only aspect of the dynamic performance of tractor-trailer combinations which has attracted much interest is their braking systems[3]. There has been a growing concern for the road safety of tractor and trailer combinations because although they have been used on roads for many years, their sizes have gradually increased, 18 tonne capacity trailers now being available. Their braking performance is normally inferior to that of other road vehicles. Tractor and trailer combinations, moving at the various national speed limits on the roads of 7-9 m/s can cause potential hazards when mixing with traffic moving generally at far higher speeds.

Although tractor ride characteristics have been extensively and successfully studied[4,5] the effect of trailers on tractor ride has apparently received no attention. Some work of relevance has however been carried out in the earthmoving and automotive industries[6,7,8]. The idea of using the trailer as a vibration absorber through a tuned hitch, as for example has been achieved for earthmoving scrapers[9], has been suggested but never studied.

Similarly, handling behaviour of tractor and trailer combinations has received little attention, despite the large volume of research into road vehicle combinations[6,10,11]. Cases of jack-knifing instabilities have however been reported during measurements of braking performance on slopes[3]. Some work has been carried out into steering behaviour of tractors alone[12,13] including a study of the axle weights necessary to retain adequate steering[14] but knowledge of the dynamics of the steering process is extremely limited. A programme of work at the Technical University, Berlin to study steering performance of tractor/implement combinations has been described[15].

The objects of this paper are to examine ride and handling behaviour of tractor and trailer combinations and to investigate possibilities for improvement.

2 Tractor and trailer ride vibration

2.1 Theoretical model

The model is shown in fig 1. There are six degrees of freedom, namely:

- z tractor vertical
- x_1 tractor longitudinal
- θ_1 tractor pitch
- z_2 trailer vertical
- x_2 trailer longitudinal
- θ_2 trailer pitch

It is assumed that the tyres can be simplistically modelled by linear springs and viscous dampers, and that the hitch has both a vertical and longitudinal resilience. Although resilient hitches are incorporated on some tractors and trailers as a sprung drawbar or an overrun braking system with spring actuator, they are included here to investigate the potential effect of a specially designed sprung hitch. Lateral, roll and yaw motion are ignored because they are assumed to be of secondary importance. Tractor lateral and yaw motions will be affected to some extent by the addition of a trailer but the frequencies tend to be less than 1 Hz because the steering response of the driver is involved. In the roll plane the hitch is assumed to be a hook and ring type, so that tractor and trailer are free to roll independently over small angles. A small rolling moment will however be produced by lateral hitch forces, since the hitch is located below the tractor roll centre.

The tractor is assumed to be a conventional two wheel drive type, so that only the tractor rear wheels have longitudinal stiffness values, all the other wheels being free rolling. This assumption must be modified for four wheel drive tractors, or driven trailer wheels. The parameter values used (table 1) were for a typical 60 kW tractor and 8 tonne trailer.

Table 1 **Parameter values for 60 kW tractor and 8 tonne trailer combination**

60 kW tractor	Mass	m_1	3000	kg
	Pitch inertia	I_1	3000	kg m^2
	Front tyre	k_{FZ}	4.0×10^6	N/m
		c_{FZ}	0.8×10^3	kg/s
	Rear tyre	k_{RZ}	4.0×10^6	N/m
		c_{RZ}	2.5×10^3	kg/s
		k_{RX}	4.5×10^6	N/m
		c_{RX}	2.5×10^3	kg/s
	Dimensions	x_{1F}	1.3	m
		x_{1R}	0.8	m
		x_{1Z}	1.1	m
		z_{1G}	0.8	m
		z_{1H}	0.3	m
8 tonne trailer	Mass	m_2	9700	kg
	Pitch inertia	I_2	12000	kg m^2
	Tyre	k_{TZ}	4.5×10^6	N/m
		c_{TZ}	0.9×10^3	kg/s
	Dimensions	x_{21}	3.5	m
		x_{2R}	0.8	m
		z_{2G}	1.2	m

The equations of motion were derived using Lagrange's method which is based on system energies. It has particular advantages for this type of system because the forces of constraint, at the hitch for example, need not be calculated. Standard computer routines were then used to calculate natural frequencies (eigen values), mode shapes (eigen vectors) and frequency response functions.

2.2 Results

The results of this analysis are presented in details in reference 16, and so that a brief summary only is given here. A comparison of the ride vibration behaviour of a 60 kW tractor with and without an 8 tonne trailer is shown in fig 2, where the frequency response functions in each of the co-ordinate directions are plotted, for a unit vertical forcing input at the tractor rear wheel. Although this type of forcing input does not represent the practical situation in which each tyre is subjected to a random ground input, it nevertheless allows a simple comparison to be made between different cases. A

D A Crolla is formerly of the National Institute of Agricultural Engineers.

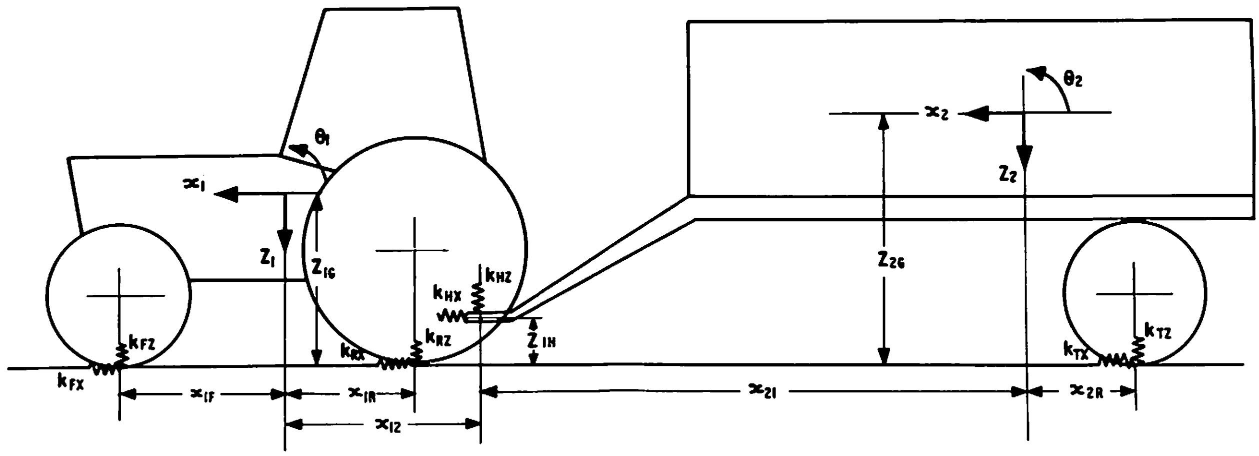
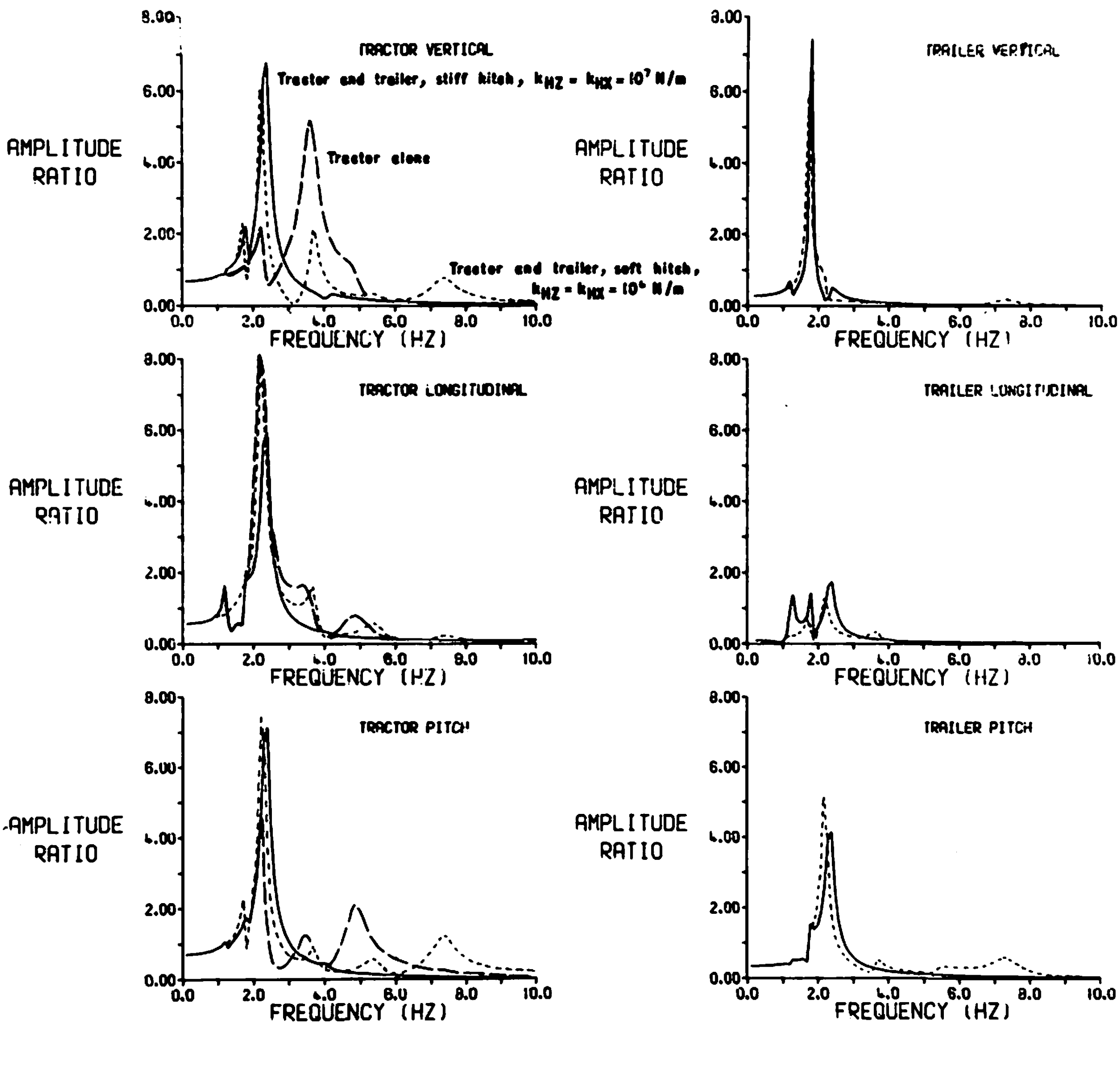


Fig 1 Tractor and trailer ride model (damping terms corresponding to each spring are omitted for clarity)

knowledge of typical ground spectra[18] is necessary in order to estimate the actual ride levels of the combination over different surfaces.

The addition of the trailer has a significant effect on the tractor ride vibration. In the vertical direction, the amplitude increases and, as would be expected, the frequency of the main component decreases from 3.6 to 2.4 Hz. In the longitudinal direction an extra mode occurs at 1.2 Hz which corresponds to the tractor and trailer vibrating in phase with each other. Tractor pitch amplitude increases drastically at the 2.4 Hz mode, which is highly coupled with tractor vertical and longitudinal motion, but the peaks at 4.9 and 3.6 Hz present for the tractor alone, disappear. For most typical agricultural surfaces, where the acceleration input spectrum is fairly constant over the range 2 to 5 Hz, tractor ride vibration will be

Fig 2 Amplitude ratios of 60kW tractor with and without 8 tonne trailer for a unit vertical forcing input at tractor rear axle (from ref 17)



considerably worse with a trailer attached, than when it is operating alone. Therefore, various parameters were altered to attempt to minimise the effect of the trailer.

There is little scope for improvement by merely incorporating a sprung hitch. It is possible to alter natural frequencies in this way, but vibration levels will only be reduced if a significant amount of damping is also included. However, since this requires a large relative deflection between tractor and trailer, it is difficult to achieve practically. Moving the hitch position also affects vibration characteristics. In general, moving the hitch forward of the tractor rear axle has a beneficial effect, and moving it upwards has a detrimental effect especially on vibration levels in the longitudinal direction. The effect of tractor and trailer size is not particularly important; increasing the size of either tends to reduce frequencies, but the basic vibration behaviour of the combination alters little.

3 Tractor and trailer handling

3.1 Theoretical model

The model used to analyse dynamic behaviour in the lateral plane is shown in fig 3. Only four degrees of freedom are necessary, namely:

- 1 tractor longitudinal
- 1 tractor lateral
- 1 tractor yaw
- 2 trailer yaw

Lateral motion of the trailer, y_2, can be described in terms of these co-ordinates, and is not therefore an independent variable. Braking forces, when applied, are assumed to be constant, so that deceleration, $\dot{U}$, is also constant.

The tyre side forces, Y_{ij}, are complex functions of vertical load, inflation pressure, ground surface conditions and slip angle, so it is necessary to make some simplifying assumptions. The approach adopted was to assume that the side force coefficient (side force/vertical load) was a function of slip angle and to use three functions to represent three different surface conditions. Since the main object of this work was to predict the onset of lateral instability, it was the initial part of this function which was important, and this too could be linearised, so that

$$\text{side force coefficient, } k_{ij} = \frac{Y_{ij}}{Z_{ij}} = k_{surface}\,\alpha_{ij}$$

where
Y_{ij} = tyre side force
Z_{ij} = tyre vertical force
k surface = surface constant
α_{ij} = slip angle

The effect of inflation pressure was included by assuming that a decrease in inflation pressure would decrease the coefficient, $k_{surface}$, slightly.

The equations of motion are given in detail in reference 17, and again they were solved using standard computer routines to calculate eigen values and vectors. Lateral instability is predicted when the real part of a complex eigen value becomes positive. The rate of divergence in an unstable condition is proportional to the magnitude of the real part which is therefore a measure of the severity of the instability. Various braking and speed conditions were simulated using a variety of tractor and trailer sizes. Results for the 60 kW tractor and 8 tonne trailer combination, whose parameter values are given in table 2, are discussed here.

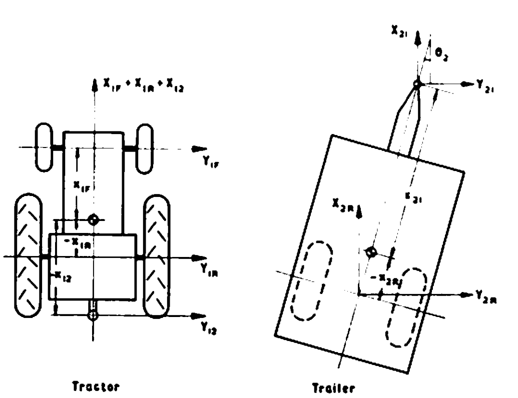


Fig 3 Tractor and trailer handling model

Table 2 Further parameter values for 60 kW tractor and 8 tonne trailer combination used in handling studies (other parameters as shown in Table 1)

60 kW tractor	Yaw inertia	c_1	3000	kg m^2
8 tonne trailer	Yaw inertia	c_2	19000	kg m^2
Ground parameters for firm dry grassland	Coefficient of rolling resistance	c	0.05	
	Coefficient of friction	μ	0.7	
	Slope of side force coefficient v. slip angle	$k_{surface}$	0.06	deg^{-1}

3.2 Results

3.2.1 Effect of speed

As the forward speed of the combination is increased, a condition of instability is eventually reached so that a steering input would result in a jack-knife. Fortunately, this happens gradually as speed is increased so that the operator would probably sense some loss of control and slow down before complete control loss occurred. Also, the speed, U_{crit}, at which instability starts to occur is above the present legal maxima of up to 9 m/s. In some cases however it is very close to these speeds, and in view of this, the present legal maximum of 9 m/s in the UK would seem to be appropriate.

Table 3 shows how U_{crit} varies when various parameters are varied. Two important trends are shown, stability decreasing for the more slippery surfaces and being improved by moving the tractor centre of gravity forward or the hitch position forward of the rear axle.

Table 3 Effect of parameter variations on critical speed at which instability occurs

Simulated conditions for 60 kW tractor and 8 tonne trailer		Critical speed at which instability occurs, U_{crit} m/s
Parameter variation	Surface	
Standard	Slippery (μ= 0.3)	13
	Firm, dry grassland (μ= 0.6)	18
	Tarmac (μ= 1)	24
Hitch 0.3 forward of tractor rear axle	Firm dry grassland	Stable at all speeds
Hitch 1 m behind tractor rear axle	Firm dry grassland	9.5
Tractor c.g. moved 0.5 m forward	Firm dry grassland	Stable at all speeds
Tractor c.g. moved 0.5 m rearward	Firm dry grassland	8.5

3.2.2 Effect of braking without wheel locking

Braking each axle without wheel locking affects the stability of the combination, because of the weight transfer between axles due to deceleration. The secondary effect of the dependence of tyre side force on the braking force transmitted by the wheel was ignored because insufficient data are available on the exact relationship. In practice, the effect will be to decrease stability slightly. Table 4 shows the effect of braking various axles on U_{crit}. Apart from the case of the trailer axle only braked, the critical speed is always lower than the corresponding value of 18 m/s for the unbraked condition (table 3), indicating a decrease in stability during braking.

3.3.2 Effect of braking with wheel locking

When a wheel is locked during braking, the side force produced reduces to zero, and the steering ability of the tyre is lost. The effect of locking each axle is summarised in table 5. Where instability occurs, the value of the real part of the eigen value is quoted as this gives a measure of the relative rate of divergence from the intended route during unstable motion.

Table 4 Effect of braking without axle locking on critical speed at which instability occurs

60 kW tractor and 8 tonne trailer on firm, dry grassland		
Axle braked	Deceleration g	Critical speed at which instability occurs, U_{crit}, m/s
Tractor front	0.10	15
Tractor rear	0.25	9
Trailer	0.39	30
Tractor rear and trailer	0.62	14
All axles	0.70	12

Table 5 Effect of axle locking on stability of tractor and trailer combination

60 kW tractor and 8 tonne trailer on firm, dry grassland			
Axle locked	Deceleration g	Speed range at which instability occurs	Relative rate of divergence during braking from a forward speed of 8 m/s
Tractor front	0.10	Stable at all speeds	–
Tractor rear	0.25	Unstable at all speeds	3.2
Trailer	0.39	Unstable at speeds above 5 m/s	0.5

Locking the tractor front axle results in stable motion at all speeds, with the combination tending to continue straight irrespective of steering angle. Locking the tractor rear axle always results in unstable motion, known as jack-knifing where the tractor and trailer fold together. Locking the trailer axle at up to 5 m/s is safe but above this speed a different instability occurs. Although not as violent as jack-knifing, this can be dangerous because the trailer swings laterally relative to the tractor which maintains a reasonably constant course.

3.2.4 Steering performance

The model can also be used to predict the steering response of the combination. Figure 4 shows a comparison of the steering trajectories for the 60 kW tractor with and without an 8 tonne trailer, assuming a step change in front wheel angle to 20° from the longitudinal being applied at a forward speed of 5 m/s on a typical road surface. The tractor alone shows a tendency to understeer, that is to run wide during the turn. However this tendency is less marked for the tractor and trailer combination because the trailer tends to push the tractor rear outwards and increases initial yaw rate. Because of its greater inertia the tractor and trailer combination is slower to reach its final yaw rate, so that after approximately 150° of the turn it has run on a wider trajectory than the tractor alone. The steering trajectory calculated from geometry by a static method, highlights the difference between the static and dynamic calculations and indicates that fairly high slip angles are being generated even at these low speeds.

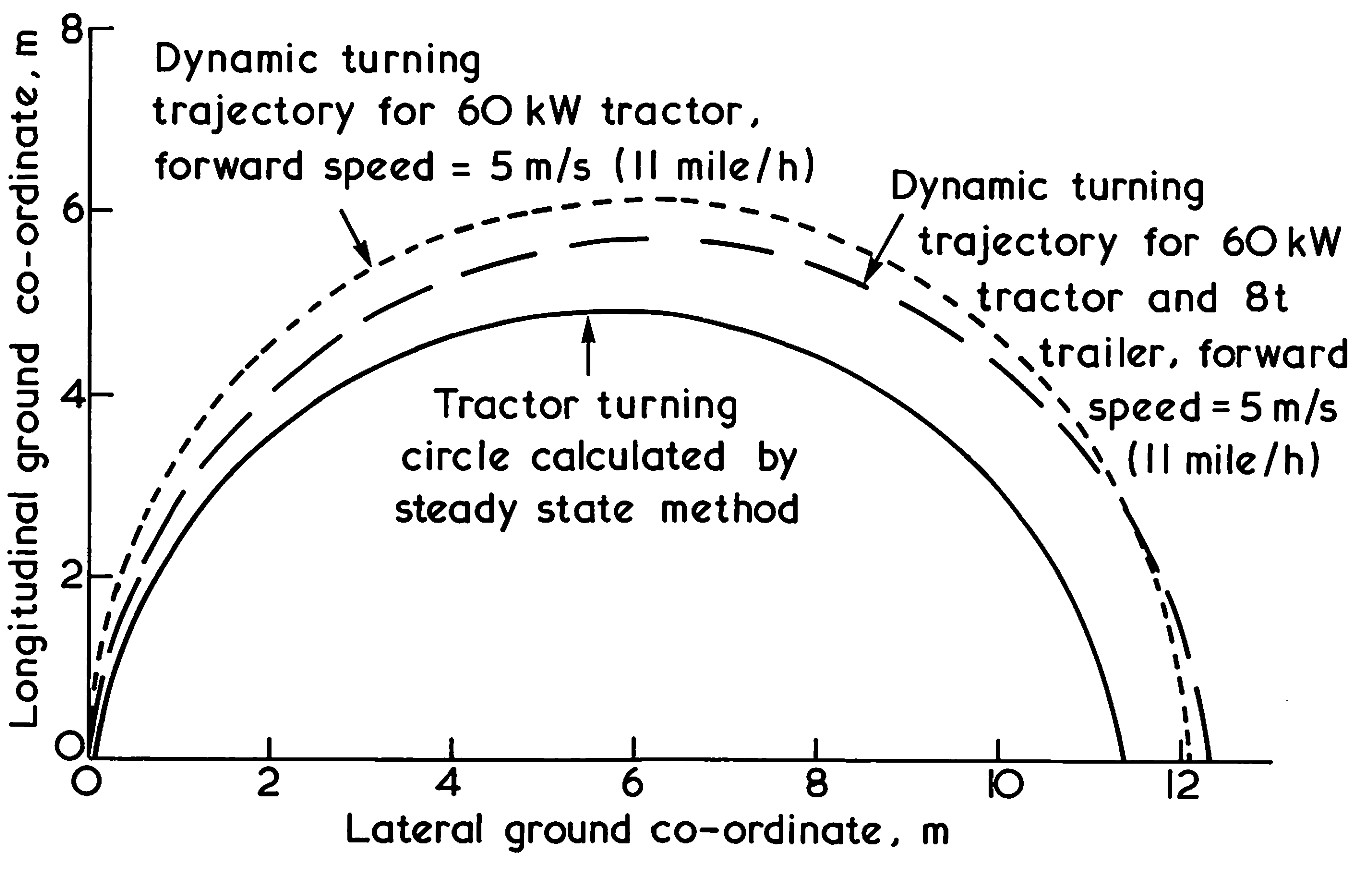
4 An agricultural transport vehicle?

Having highlighted the shortcomings of the tractor and trailer combination in both ride and handling behaviour, it is interesting to consider methods if improving performance. The benefits of higher speed transport operations have been discussed widely[1,2], but clearly the present tractor and trailer combination is not suited to this adaption. Although the more detailed studies[16,17] showed that some advantage could be gained by minor modifications, such as hitch position, the scope for significant improvement appears to lie in changing the configuration of the combination to resemble an off-road version of an articulated lorry.

An example of the effect of this change on the vehicle ride characteristic is shown in fig 5 where the amplitude ratios in the vertical direction are compared for each vehicle. The weight of the hypothetical specialised transport vehicle is the same as the tractor and trailer; the only differences are the layout of the tractor unit, the tyres and the hitch position. Although the specialised transport vehicle was assumed not to incorporate wheel suspension for the comparison, further calculations incorporating a front suspension showed that the amplitude ratio could be reduced even further.

A comparison of the stability of the two types of combination

Fig 4 Steering trajectories of the cg of a 60kW tractor with and without 8 tonne trailer for a 20° step steering input on a road surface



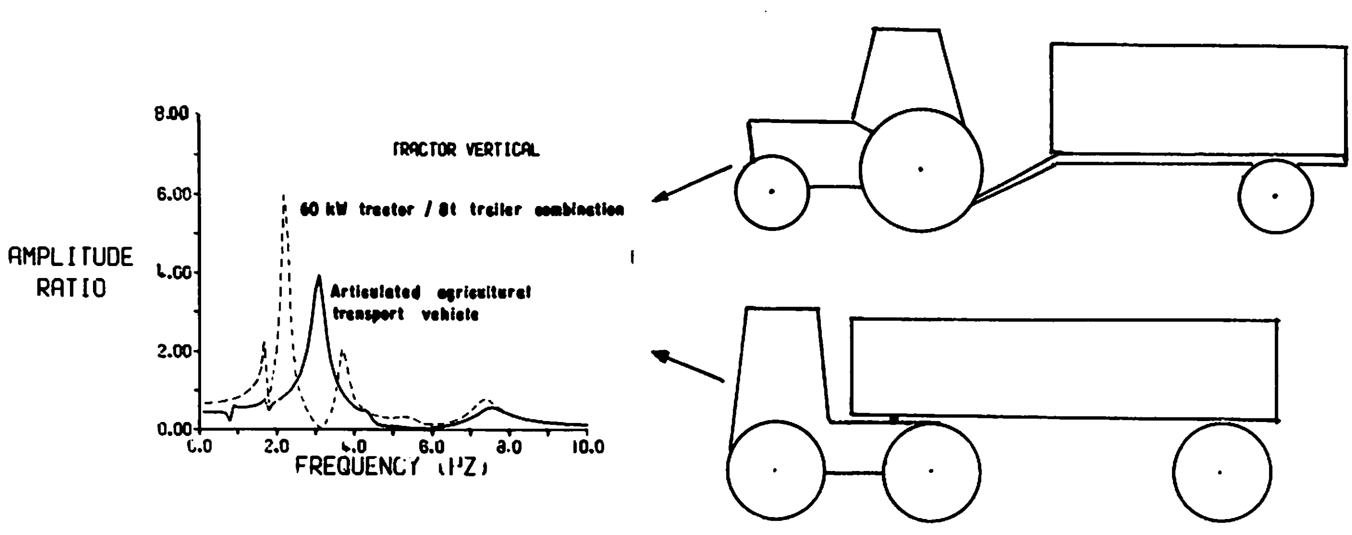


Fig 5 Comparison of amplitude ratio in vertical direction for tractor and trailer combination and specialised transport vehicle (from ref 17)

showed that the specialised transport vehicle could be operated safely at far higher speeds, stability being retained up to 55 m/s. A comparison of the hypothetical vehicle with an articulated road vehicle showed that their stability characteristics were similar[17], which implies that the agricultural vehicle would have similar characteristics of safety to present road traffic. Instabilities during axle locking were similar for both the tractor/trailer combination and the specialised transport vehicle, although the trailer swing instability did not occur with the specialised vehicle until the slightly higher speed of 7 m/s and it was also slightly less severe. One of the advantages of the specialised vehicle design however is that, because approximately half the tractor unit weight is carried on the front axle, a substantial braking force can be generated. From stability considerations this is the preferred axle to brake because even if wheel locking occurs, stability is retained.

Besides the improvements in dynamic behaviour offered by the modified layout, a further advantage is that the semi-trailer units could be operated on the road if necessary by standard tractor units of present commercial articulated lorries, provided a standard fifth wheel coupling is used. The agricultural tractor units would then be used to operate the semi-trailers for off-road transport and leave the trailers at roadside positions for the road tractor units to pick up.

5 Conclusions

5.1 A study of a simplified linear vertical longitudinal plane model of a tractor and trailer combination indicated that tractor ride vibration levels increase as a result of operating the tractor with a trailer attached, the most significant increase being in longitudinal and pitch motion.

5.2 A linear horizontal plane model showed that a speed-dependent handling instability existed which was more pronounced when braking forces were applied at the tractor. Locking different axles had different effects. Locking the tractor front axle retained stability, locking the tractor rear axle resulted in a jack-knifing instability and locking the trailer axle caused a milder instability in which the trailer swung laterally.

5.3 Although some improvements to the dynamic behaviour could be made by minor geometric modifications, greater scope for significant improvement lay in changing the configuration to resemble an off-road version of a commercial articulated lorry. Predictions indicated that this vehicle concept could be designed to operate safely both on and off the road at higher speeds than the current road speed limits for tractors and trailers.

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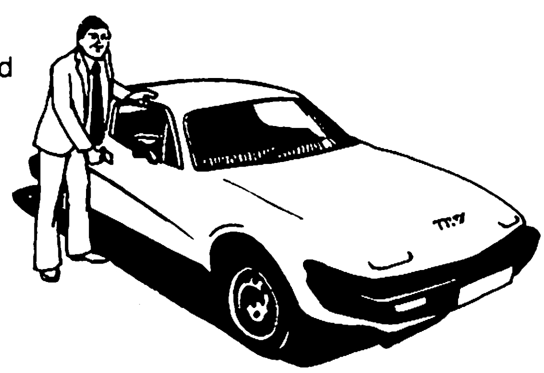

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