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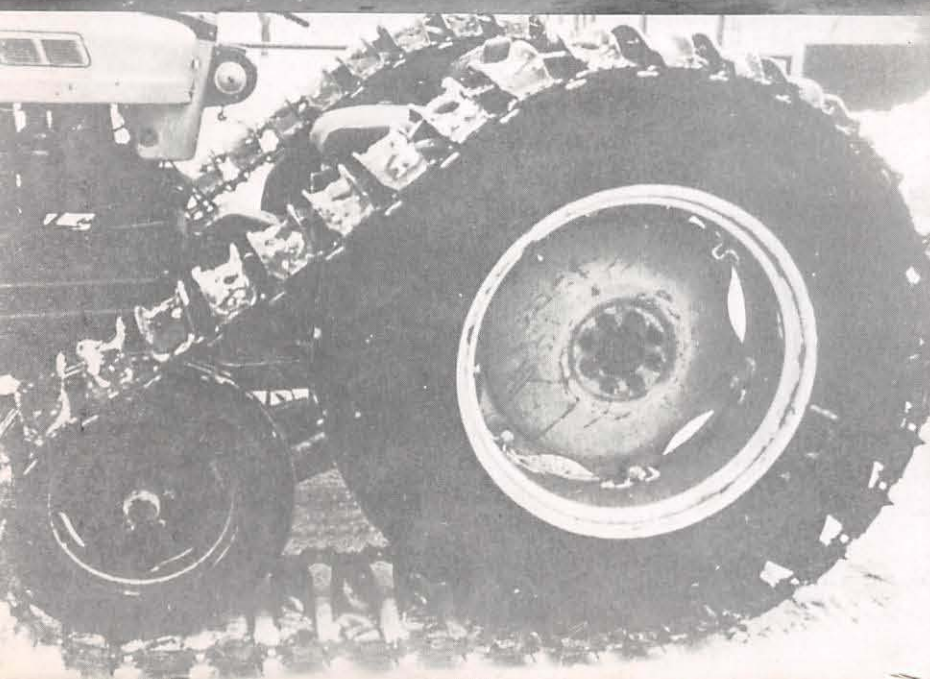

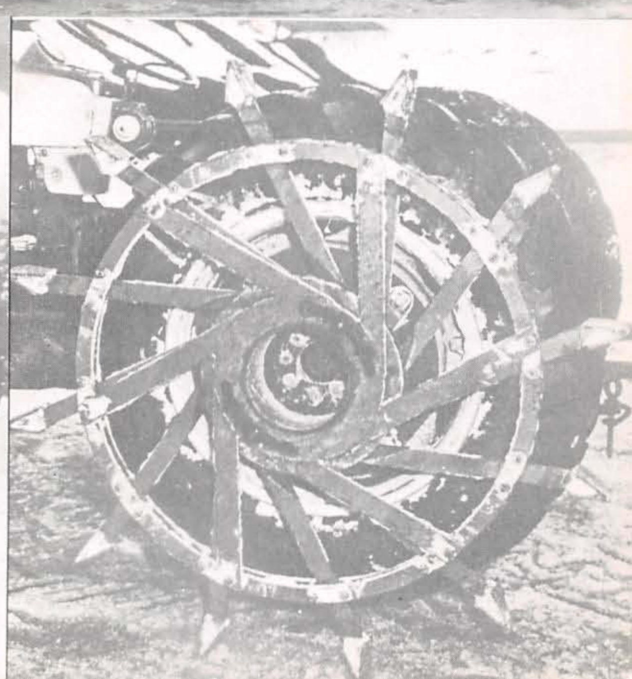

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CONTENTS

Front cover pictures: Top - two matched Ford 5000 tractors, one fitted with 18.4-30 drive tyres, the other with 13.6-38 drive tyres, used in field performance experiments at NIAE. Left - Half-tracks used in Southwell's experiments in Canada. Right - Strakes used in Southwell's experiments in Canada.

Work days for field operations

G Spoor

THE number of days available for field work associated with the soil is frequently at the centre, either directly or indirectly, of farm planning decisions and day to day problems. The number and distribution of available work days influence the type and acreage of crops grown and the labour and machinery requirements.

From past experience, a farmer knows what is possible on his own farm and plans accordingly for the future. Even so, he often runs into severe problems in bad years and has to work when soil conditions are unfavourable. Soil structural damage sometimes results. He is particularly interested in finding ways of being able to work over a wider range of conditions without increasing soil damage. Where damage does occur, and it inevitably will, knowledge of how it can be rectified is required.

Investigations related to work days are proceeding in numerous specialist areas, such as in drainage, traction, soils, meteorology, management, agronomy and machinery manufacture, and are directed towards quantifying and finding ways of extending the working season. Unfortunately, much of this work is happening in isolation and the individual worker is not always fully aware of the relevance and relative importance of his own contribution. It is very easy, in isolation, for one particular aspect of a problem to be given rather more importance and another less consideration than it deserves.

At this time when new ideas on cultivation requirements and crop production techniques are common, and larger, heavier, more powerful and greater capacity tractors and implements are being introduced, it was considered appropriate to arrange for a discussion on their impact on work days. The most fruitful discussion could best be achieved by bringing together farmers and specialists from a wide range of disciplines, all with an interest in this problem.

W R Butterworth and G Spoor, joint conference convenors.

The prime aim of the Conference has been to allow an exchange of information and ideas to put all the various aspects of the work day problem into perspective. From this it should be possible to apply present knowledge more effectively and to highlight the areas where work needs to be done in the future. This in both the short and the long term should enable farmers and other soil operators and manipulators to extend the days available for work without incurring unacceptable soil damage and, where damage does occur, to repair it rapidly and successfully.

A farmer's viewpoint and requirements

F H Birkett

Summary

SOIL pollution and physical damage should be at the forefront of the farmer's mind. Care must be taken to eliminate, or, at least, to keep to the absolute minimum, damage to soil structure. Where crop considerations necessitate field operations which put the soil structure at risk, reparation must be made by the use of the correct equipment, properly used.

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SOIL is our heritage, it supports us, and will be required by all future generations. We should not waste it by damage or contamination; yet so often we damage it without thought. How often is oil allowed to run on to the field by a mechanic repairing a tractor or implement? Or, to come nearer to the Conference subject, how many of us drive a car across a field when we could just as quickly walk? Ideally not one wheel should be driven on to a field without good reason.

Certainly, circumstances often force us to damage soil. Often the crops we have grown must be harvested in autumn and winter conditions, such as those experienced in 1976/77, which render soil particularly vulnerable. So how can we mechanise our farming and achieve the least amount of permanent damage?

First the land must be well drained and the drainage system well maintained. Next a good crop rotation not only combats disease, but spreads the work load of men and machines. Good planning is essential.

The other vital factor is that the crops grown maintain an acceptable organic level in the soil. For example, on our silt land in South Lincolnshire the organic level is about 2½% in an arable situation. This level does not seem to vary much where a good rotation is followed, unless severe mechanical damage is done. A good rotation would be:—

Potatoes	1 in 8
Sugar beet	1 in 6
Peas	1 in 6
Cereals	1 in 3
Carrots	1 in 8
Brussel sprouts	1 in 8

This is not easy to work into an exact rotation; out beet and peas have to have one break of four years one of eight years which averages six years.

We also sow grass under winter wheat, harvest the wheat and apply nitrogen to the grass to encourage rapid growth. The land is then ploughed in late November or December, and it is often found that it is much drier than stubble without grass.

Machinery for a particular crop should be able to cope with its function in half to two thirds the available time, thus making it possible to wait for the best possible conditions and then to complete the operation quickly and well.

This machinery must be well maintained to minimise breakdowns. When an operation is complete, the machinery used must be cleaned and painted or treated with a rust preventative as necessary. Worn parts should be carefully noted so that during the winter months when the implements all go through the workshop these can be replaced or repaired.

To get the best out of machines with the greatest amount of ease for the men, one has to think ahead. Outputs must be known and recorded. A work plan should then be produced each year. Ideally, each man should have his own tractor and, as far as possible, use the same implements each time they are needed.

All this helps to minimise the damage we do to the soil structure. But with root crops which are autumn harvested, we must press on whenever conditions are "possible". Autumn almost always gets wetter, and the days grow shorter. So soil moisture level rises. Usually at this time of year it is better to keep going, making best efforts to repair the soil. Each day's harvested land should be chisel ploughed on the day of harvest.

We keep at least one chisel plough following potato and beet harvesters. Tractor drivers take the shortest route to and from harvesters, never running on the chisel ploughed land. When harvest, or any other operation, is complete it should not be possible to find one tyre mark on a field. In fact the only such marks ever left on a field should be tram lines used by sprayers and fertiliser distributors.

Dwelling just a moment longer on fields damaged by autumn harvesting, these should be carefully recorded so that the first opportunity can be taken to "deep bust" them. The opportunity for this subsoiling will most likely come when a crop of peas or wheat has been harvested in dry conditions.

Subsoiling, however, should only be carried out when necessary; this topic will be covered by other speakers later today. I would however like to point out that I now carry a spade at all times as well as a spud which I have always carried. The motto is "dig before you bust". Busting is aimed at breaking up a soil pan. If the subsoiler does not reach down to this pan, or if no significant pan exists, busting will possibly do more harm than good by breaking up the soil structure.

Referring now to normal cultivations for a moment, it is useless to send any cultivation implement into a field until the object of doing so is clear. It is necessary to work soil to a depth where seeds can be placed on a firm bottom. Cultivator drivers should drive in exactly the correct place, just as does the driver drilling the seed. The whole area worked should receive the same ground pressure. We use double rear wheels and modified furrow presses to ensure this. Tractor wheels should never run in the same place twice. The "press" on a drill should never be used to force coulters into the soil: only to maintain the coulters at the correct depth, ie at the bottom of the cultivations.

We are now able, with power steering on tractors, to think about wide front wheels. Flotation tyres 13.6 x 16 on the front at about 55 kPa (8 lb/in^2) are worthy of consideration. Rear tyres at the moment are run at 96–150 kPa (14–22 lb/in^2) but could modern design make it possible to reduce this to 55–96 kPa (8–14 lb/in^2). Traction slip is the most damaging factor. We must do all we can to minimise it.

When tyres squeeze silt soil it becomes anaerobic unless it is repaired. Therefore, soil and cultivations HAVE to be right at drilling times. Low ground pressures and good traction are very necessary.

The above observations have been brief and based only on the "common sense" which is essential in every farmer. But perhaps they may serve as a timely reminder. We must look after this soil of ours, its all we have.

Paper presented at the Autumn National Conference (in association with South Eastern Branch) of the Institution of Agricultural Engineers, at Marks Tey Hotel, Marks Tey, Essex, on 11 October 1977.

Erratum

A correction should be made to table 1 of the paper by J G Elliott which was published in Vol 32 No 2. Herbicide consumption in various countries is in metric tonnes, not '000 metric tonnes as printed. A consequent error arises in quoting the consumption in USA as 212 M tonnes. This should be 212 000 tonnes.

Effects of timeliness of soil-engaging operations on crop yield

R H Jarvis

Summary

AVAILABLE evidence on the timing of cultivation, planting and harvesting is reviewed. Effects upon the yields of a number of arable crops are examined and conclusions are drawn as to the sensitivity of maximum yield to sowing date.

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THE variables discussed are time of primary cultivation, time of planting or sowing and, in the case of root crops, time of harvesting. A large amount of trial evidence is available on the effects of time of sowing but very little on the other two topics. Operations such as the timing of post-planting cultivations have not been considered because of the virtual absence of experimental data. Even in the cases where a reasonable number of trial results is available, the amount of useful information which can be extracted is restricted. This arises partly from the limitations of the experimental work which was usually confined to a small number of dates, sites and seasons, and partly from the practical problems arising in experimental work of this type, particularly that of maintaining realistic husbandry standards on small plots.

1 Time of primary cultivation

The effect of date of ploughing a ley, before drilling winter wheat, has been investigated by several workers. McClean (1966) recorded a 5% reduction in yield when a Cockle Park type ley was broken in mid-September rather than in July. Hanley, Jarvis and Whitear (1961) tested the effect of ploughing a one-year clover ley at intervals of three weeks in early autumn; they reported a reduction in yield of 7.5% from ploughing in mid October compared with late September but early September ploughing also led to a small reduction. Meadowcroft (1970), on the other hand, found that ploughing a clover ley in late August or late September had no effect on the yield of the subsequent wheat crop, although the later date gave a 4% reduction in yield when pure grass swards were broken. In each of these trial series the sowing date was common to each time of ploughing treatment.

The data quoted indicate that date of ploughing is likely to affect yield to a small extent and suggest that the effect may be modified by the botanical composition of the sward. They do not enable any conclusions to be drawn regarding an optimum date of ploughing or on interactions with soil, site or season.

The time at which a ley is ploughed is likely to affect the nitrogen supply to the subsequent crop over a considerable period and effects on tilth are usually more obvious than when for instance a cereal stubble is broken up at different dates. It may therefore be inferred that the effect of timing the primary cultivation in other cropping sequences is likely to be less pronounced than the rather small effects discussed above.

2 Time of sowing or planting

There is a number of problems in reporting the results of experiments where the dates of sowing or planting have varied in different years, principally because the calculation of average figures presupposes a linear response to time of sowing over the range of dates covered by a particular treatment. However, the method used by Hull and Webb (1970) satisfactorily overcomes this problem. They expressed treatment yields as percentages of the mean yield each year to eliminate seasonal differences in mean yield, and sowing date was expressed as days after the earliest sowing date in the whole trial series. Quadratic regressions were then calculated for both root yield and sugar yield on sowing date. These accounted respectively for 83% and 78% of the variance and are discussed in more detail in section 2 (iv) below.

The same method has been applied where possible to other authors' data in the remainder of the following sections; the regression equations are given in table 1.

(i) *Winter wheat.* Much of the earlier work compared no more than two sowing dates and tended to show little or no depression in yield when sowing was delayed from late September to mid-October; November sowings yielded less well. Mundy and McClean (1965) reported results of this type with the variety Cappelle Desprez; there is evidence in their results of differences between seasons and possibly between sites in the effect of delayed sowing.

Recent trials at Drayton EHF have produced more precise results (MAFF 1977 b). These were carried out in the harvest years 1973 – 75 using three sowing dates and a number of varieties. Among the latter certain consistent similarities and differences were evident. Thus Cappelle Desprez and Maris Widgeon both showed a similar pattern while Maris Freeman and Maris Ranger, although similar to each other, appeared to behave differently from the first two. Fitted quadratic regression lines are shown in fig 1; the regression accounts for 66% of the variance in the case of Cappelle and Widgeon and 72% in the case of Freeman and Ranger. The highest yields of Cappelle and Widgeon were obtained from late September sowings while with Freeman and Ranger early to mid-October gave the best results. Even within the limited period investigated, late sowing had a much greater effect on the first two varieties than on the latter. The other varieties included in the trial (Atou, Bouquet and Maris Huntsman) showed considerably more year to year variation in their response to sowing date.

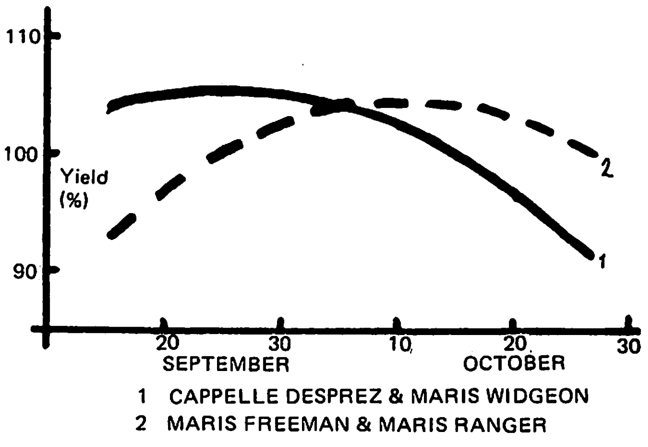


Fig 1 Effect of sowing date on yield of winter wheat (as % of mean).

(ii) *Spring wheat.* Results from trials at various EHFs were reported by Francis (1974). The most comprehensive data were for the Arthur Rickwood EHF where four varieties were sown at three dates in each of the years 1966 – 68. There was no indication of any interaction between variety and sowing date (either at the Rickwood EHF or elsewhere) and all the varietal figures have been pooled to demonstrate the seasonal effect which was recorded (fig 2). The quadratic regression for 1966 – 67 accounts for 86% of the variance and that for 1968 for 95%. Both curves suggest a greater sensitivity to sowing date than with winter wheat but whereas in 1966 – 67 the optimum date was in early April, in 1968 the best yields were obtained from sowing 3 – 4 weeks earlier.

R H Jarvis MA dip Agric (Cantab) is from Boxworth Experimental Husbandry Farm, Cambridge.

Paper presented at the Autumn National Conference (in association with South Eastern Branch) of the Institution of Agricultural Engineers, at Marks Tey Hotel, Marks Tey, Essex, on 11 October 1977.

Table 1 Quadratic regressions of yield as % of mean (y) on sowing date (d)

Crop etc	*Data source*	d_o	*Regression*
Winter wheat: grain yield			
Cappelle Desprez and Maris Widgeon	MAFF (1977 b)	14 Sept	$y = 104.1 + 0.2793\,d - 0.0140\,d^2$
Maris Freeman and Maris Ranger	MAFF (1977 b)	14 Sep	$y = 92.8 + 0.9048\,d - 0.0174\,d^2$
Spring wheat: grain yield			
Rickwood EHF 1966 – 67	Francis (1974)	5 Mar	$y = 79.6 + 2.3909\,d - 0.0392\,d^2$
Rickwood EHF 1968	Francis (1974)	5 Mar	$y = 118.7 + 0.3569\,d - 0.0287\,d^2$
Spring barley: grain yield			
Boxworth EHF	Francis (1974)	4 Mar	$y = 113.3 - 0.0962\,d - 0.0082\,d^2$
Bridgets EHF	Francis (1974)	7 Feb	$y = 106.8 + 0.7657\,d - 0.0158\,d^2$
High Mowthorpe EHF	Francis (1974)	4 Mar	$y = 108.0 - 0.3081\,d - 0.0002\,d^2$
Sugar beet: sugar yield	Hull and Webb (1970)	12 Mar	$y = 106.3 + 0.212\,d - 0.009\,d^2$
Potatoes: ware yield			
Sprouted	)Baldwin (1964)	(18 Mar	$y = 97.9 + 0.8275\,d - 0.0218\,d^2$
Unsprouted	)Palmer and Jarvis (1967)	(18 Mar	$y = 99.5 + 0.9457\,d - 0.0270\,d^2$
Winter oilseed rape: seed yield	MAFF (1977 a) MAFF (1977 c)	12 Aug	$y = 88.5 + 1.2187\,d - 0.0214\,d^2$

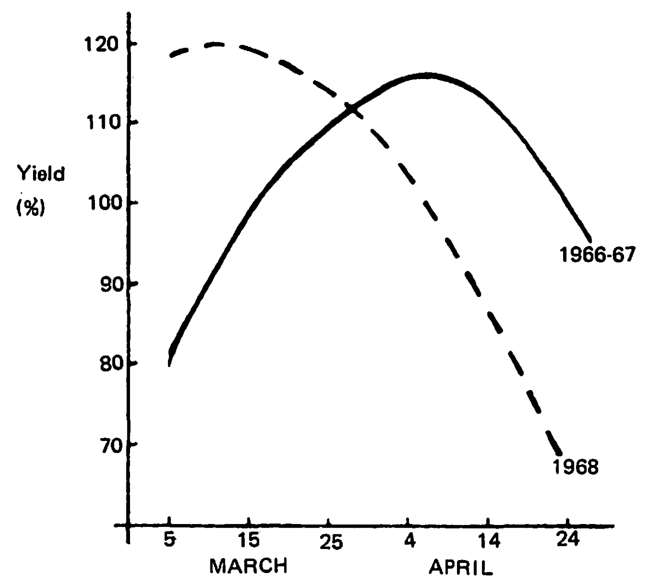
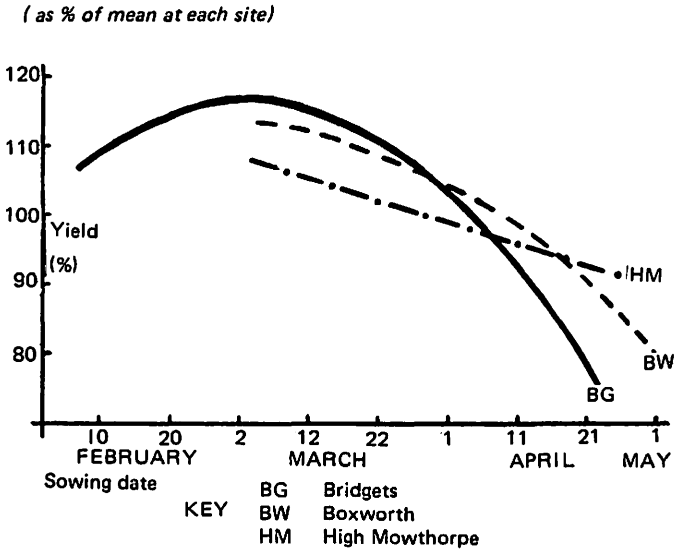


Fig 2 Effect of sowing date on yield of spring wheat (as % of mean).

(iii) *Spring barley.* Francis (1974) also reported on a number of trials with spring barley and it is with this crop that the most comprehensive data are available. Several varieties were included at the different centres but, as with spring wheat, there was no evidence of any varietal effect on the response to sowing date. Fitted regression lines for three centres are shown in fig 3; in each case three years' results were included. The proportion of the variance accounted for by the quadratic regression was 67% at Boxworth, 75% at Bridgets and 67% at High Mowthorpe. The sowing dates tested spanned the apparent optimum only at Bridgets although the Boxworth curve suggests very strongly that, as at Bridgets, a late March or early April sowing would have given the highest yields. The differences in the rate of decline of yield at the later sowing dates are also of interest. Soil types at Bridgets and High Mowthorpe are similar but the latter's more northerly latitude reduced the harmful effects of late sowing. Boxworth is situated in an area of lower rainfall and greater potential evapo-transpiration than either Bridgets or High Mowthorpe. The effects of late sowing, however, were intermediate between those at the other two EHFs probably because the soil is much more moisture-retentive.

Fig 3 Effect of sowing date on yield of spring barley (as % of mean at each site)



(iv) *Sugar-beet.* The effect of sowing date on sugar yield has been determined by Hull and Webb (1970). Sowing date had relatively little effect until mid-April but thereafter yield declined more rapidly. The results in individual years suggest that early sowing is less advantageous, and may indeed tend to depress yield, in cold late springs.

These trials were carried out between 1963 and 1967 with rubbed and graded seed drilled at 4 cm spacing and subsequently singled by hand. Since then varieties more resistant to bolting and hence less likely to be adversely affected by early sowing have become available. More important, perhaps, has been the move towards drilling-to-a-stand and it is possible that these factors might result in a rather greater advantage for early sowing and a more pronounced decline in yield from sowings made in late April or early May.

(v) *Potatoes.* The amount of experimental data is limited but results obtained from planting both sprouted and unsprouted seed of King Edward on three dates in each of three years have been published by Baldwin (1964) and Palmer and Jarvis (1977). Both sets of data show considerable variations in response to time of planting from year to year but on average both give similar results. Quadratic regression lines fitted to the pooled data account for only 30% of the total variance for sprouted seed and 41% for unsprouted, because of the considerable annual variations. On average, yield fell appreciably when planting was delayed beyond the third week of April and the rate of decline was more rapid with unsprouted than with sprouted seed.

These conclusions are supported by results reported by Munro and Scourey (1977) who showed in a comparison of two planting dates that with both King Edward and Pentland Crown the yield of normally-sprouted seed usually increased when planting was delayed from late March to mid-April. However, in a year when planting was delayed from mid-April to early May, yield fell appreciably. With "mini-chitted" seed the effect of planting date up to mid-April was more variable but at a later planting date the yield dropped much more markedly than with normally-sprouted seed.

(vi) *Winter oilseed rape.* Trials on drilling date for winter oilseed rape have been carried out at several EHFs in recent years. The most complete sets of data are available from Boxworth (MAFF 1977 a) and Terrington (MAFF 1977 c) and agree quite closely with each other. At both farms two varieties were included in the trials in 1974 and 1975 and at Terrington only, three in 1976; there is no evidence to suggest any consistent interaction between variety and

→*page 86*

sowing date. The quadratic regression line fitted to date from all varieties at both centres shows that on average the best yields were obtained from sowings made in the first two weeks of September. However, the regression accounts for only 29% of the variance and year-to-year differences were appreciable. This is well illustrated by the Boxworth data for 1974 and 1975. The considerable depression in yield which resulted from late drilling in the autumn of 1974 may be attributed to cold, wet weather in October and November which delayed crop emergence and subsequent growth; in the warmer autumn of 1975 late drilling produced much more satisfactory results.

3 Time of harvesting

(i) *Sugar-beet*. Hull and Webb (1970) investigated the effects of time of lifting the crop as well as time of sowing. There was no interaction between these two variables and the average effect of harvest date on sugar yield as shown by the fitted quadratic regression line shows a steady increase in yield up to the end of October but little change after early November. The regression accounts for 93% of the variance and there was relatively little variation in the results from year to year.

(ii) *Potatoes*. Considerations affecting the time of lifting early potatoes are both economic and agronomic. The length of the period in which the product of yield and unit price is at the maximum level may vary for many reasons outside the farmer's control. In general terms, the grower requires to be able to lift the largest possible volume in the shortest possible time.

Turning to maincrop potatoes, the normal practice is for growth to be stopped by destroying the haulm some three weeks before lifting. There is usually comparatively little bulking after early September (MAFF 1969 b) but in some seasons growth may continue to a much later date (MAFF 1977 d).

After haulm destruction yield, particularly saleable yield, may decline because of disease (eg blight) or pest damage (eg slugs). The harvested yield may also decline because of the difficulty of recovering the crop in wet soil conditions. There is little quantitative data available but in a difficult season reductions in ware yield of up to 30% have been recorded when harvesting was delayed from early September to October (MAFF 1969 a).

Apart from effects on yield, there is evidence (Patzold and Dambroth 1970) that the tubers may become more susceptible to mechanical damage as soil temperature falls and moisture content increases. The actual incidence of damage may be increased by the more vigorous treatment needed for separation in difficult soil conditions late in the season; and the effects of damage may be more severe because of the difficulty of adequately curing a crop which has been lifted cold and wet.

4 Discussion and conclusions

The amount of data concerning the timing of primary cultivations is insufficient to warrant further discussion. In the case of time of sowing, however, certain general conclusions can be drawn. For winter wheat, there is evidence that the effect of time of planting varies with variety; with spring-sown wheat and barley and winter oilseed rape there is evidence that it does not. The data for spring barley provides a good illustration of differential effects at different sites but with most crops there is insufficient evidence to explore this possibility. In several cases, particularly spring wheat and winter oilseed rape, there is clear evidence of year to year variations in response to time of sowing. However, there is very little indication from the available data that the actual length of the optimum sowing period varies appreciably from year to year.

From the regression equations given in table 1, periods when sowing or planting would have given within 5% of the maximum yield have been deduced where possible and their duration is shown in table 2. Clearly caution is needed in interpreting these figures but it is interesting to note that in no case was the period less than 21 days and more usually it extended to about 30 days. There appears to be no consistent difference between autumn and spring sown crops in this respect.

The lack of precision attached to these tentative conclusions must be stressed but it should be borne in mind that the effect of sowing date is compounded of the effects of weather conditions before sowing in as far as they affect seedbed quality, soil moisture content and temperature at the time of sowing, and weather conditions and day length subsequent to sowing. In addition, interactions between sowing date and the incidence of pests (eg frit fly), diseases (eg mildew) and weeds (eg blackgrass) may often occur. It is therefore extremely doubtful whether the very considerable experimental effort which would be required to quantify the effects of all these factors and their aggregate effect on crop yield would be justified in terms of value to the farming industry.

The data concerning date of harvesting root crops are again limited. In general they indicate that in practice sugar-beet are often harvested too early and potatoes too late. However, later harvesting of beet might well interfere with the timely sowing of the following wheat crop and would be resisted by farmers for this reason. With potatoes, on the other hand, it appears that in most seasons a move to earlier harvesting would be entirely advantageous, provided harvesting and storage techniques were of an adequate standard.

Table 2 Sowing periods giving 95% or more of maximum yield

Crop	*Duration of period (days)*
Winter wheat:	
Cappelle Desprez and Maris Widgeon	>29
Maris Freeman and Maris Ranger	34
Spring wheat:	
1966 – 67	24
1968	>21
Spring barley:	
Boxworth	>21
Bridgets	38
Sugar-beet	>36
Potatoes:	
Unsprouted	28
Sprouted	32
Winter oilseed rape	31

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Soil factors influencing work days

R J Godwin and G Spoor

Summary

A WORK day depends upon the soil's ability to withstand loads applied by the tractor and implement. This is dependent upon its shear strength. The shear strength increases with soil density and with decreasing moisture content as the soil dries from saturation to the lower plastic limit.

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A WORK day can be considered to be a day on which a farmer is able to carry out the operation he wishes on his soil with either no soil structural damage or with a minimum acceptable amount. On this day, the soil must —

(a) be able to withstand the vertical and horizontal loads applied by the tractor and implement to prevent unacceptable sinkage and slip;

(b) be in a condition where it can be manipulated in the desired way without serious structural damage or compaction.

The ability of the soil to resist these loads is dependent upon its mechanical or shear strength which develops as the soil is moved; the greater the strength, the greater the resistance to sinkage and the better the traction. If the soil shear strength is insufficient to withstand the external loads without excessive sinkage or slip, work will not be possible. Work can only proceed on that day if the equipment can be modified to reduce the loads to values which the soil can support. There are, however, limits to the modifications that can be made.

Soil comprises particles and groups of particles arranged into aggregates or structural units. When loaded, the soil can deform in two ways dependent upon the shear strength for each type of deformation. Either the individual particles or aggregates can slide over one another, remaining unchanged, or the aggregates can be broken during movement. The actual movement takes place where the resistance is least. It is convenient to recognise two forms of shear strength —

(a) bulk shear strength — the resistance offered to movement by a realtively large volume of soil aggregates or clods;

(b) clod shear strength — the resistance offered by the individual clod or aggregate.

Soil structural damage occurs when the aggregates are broken or destroyed during soil working.

The main factors which influence shear strenqth are —

(a) moisture content or suction;
(b) packing density;
(c) texture (particle size);
(d) organic matter content.

The solid line in fig 1 shows the changes that Nichols (1932) found in bulk shear strength with changes in moisture content; these are also related to the upper and lower plastic limits. The increase in shear strength with decreasing moisture content from the upper to the lower plastic limit is clearly seen. The lower plastic limit represents the maximum moisture content where a farmer can break clods during seedbed preparation without causing structural damage. It is a condition frequently accepted as the upper moisture limit for working soils in agriculture. The removal of moisture below the lower plastic limit reduces the attractive force between aggregates and hence there is a slight reduction in shear strength. Fig 2 shows the changes in clod shear strength for a Wicken series clay soil with moisture content; these are also related to the upper and lower plastic limits.

It can be seen that at high moisture contents the clods are very weak and are therefore very susceptible to deformation. The strength of the aggregates at these moisture levels is mainly due to the strength of organic bonds. The higher the organic matter content the stronger the aggregates. Aggregates produced on fine sand and silt soils tend to be extremely weak.

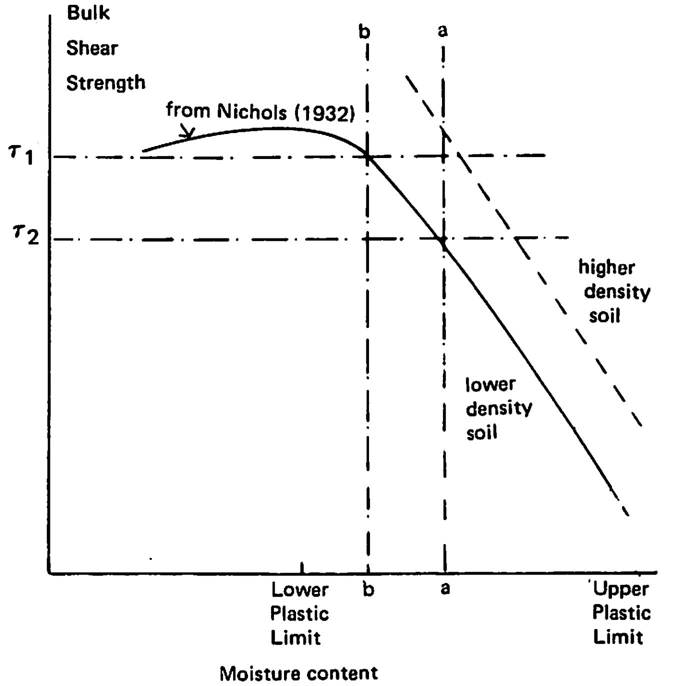

Fig 1 Relationships between bulk shear strength and moisture content for two soil densities.

At any particular moisture content the bulk shear strength increases with soil bulk density. This is due to the increased interlocking between soil aggregates and clods which increases the internal friction of the soil and is shown by the broken line in fig 1. The angle of internal friction for a range of soil densities in a sandy loam soil (Cottenham series) is illustrated in fig 3 from Godwin (1974).

The effect of density and moisture content on shear strength can be illustrated using fig 1. Consider a particular shear strength τ_1

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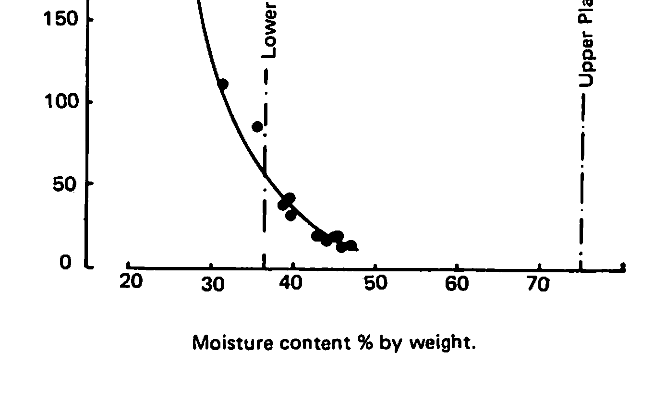
Fig 2 Relationship between clod shear strength and moisture content.



R J Goodwin and G Spoor are from the National College of Agricultural Engineering, Silsoe.

Paper presented at the Autumn National Conference (in association with South Eastern Branch) of the Institution of Agricultural Engineers, at Marks Tey Hotel, Marks Tey, Essex, on 11 October 1977.

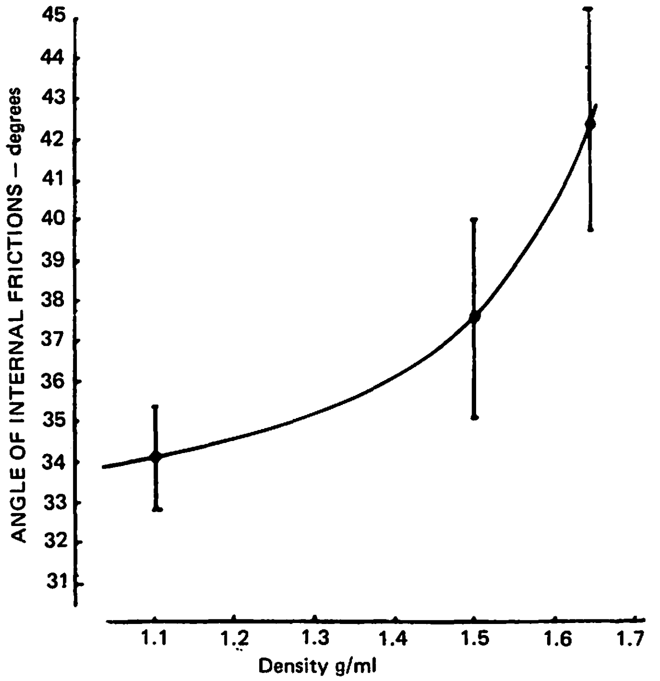
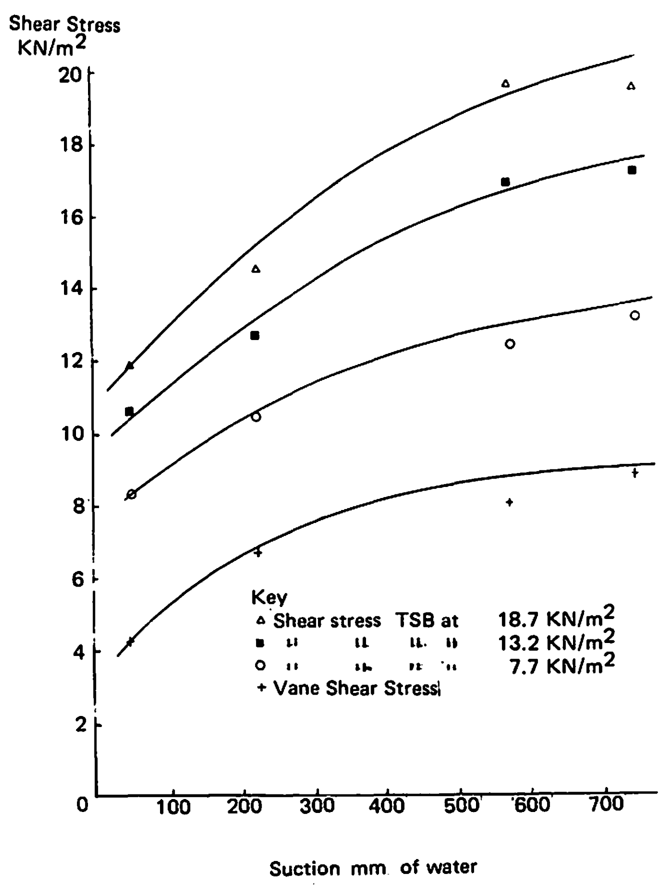


Fig 3 Friction angle versus density for a sandy loam soil, cottenham series. From Godwin (1974).

required to support a given tractor. If the soil moisture content is at (a) the low density soil would be unable to support the tractor and work would not be possible until the soil had dried to (b). The higher density soil due to its adequate shear strength, could support the load immediately and work would be possible. The only way that it would be possible to work with the less dense soil at moisture content (a) would be to reduce the required shear strength to τ_2 by modifying the equipment.

Figure 4. Shear stress, suction relations for the vane and torsional shear box, (at 3 normal stresses).



Cultivated soils usually have a lower density than undisturbed soils, hence lower shear strengths and less ability to support loads and develop traction at high moisture contents. Recent work, by the authors, has shown that there is little difference in the bulk densities and strength of a range of cultivated tilths prepared in the autumn, when worked into a seedbed during the following spring. With cultivated tilths it is necessary to wait for the moisture content to fall and the strength to increase before work can commence. The faster the drying rate, the earlier the soil can be worked.

The moisture content of the soil and hence its strength is influenced by drainage, evaporation and transpiration. There is, however, a limit to the effect which the first two have in reducing the soil moisture content from saturation. As the water table falls in the soil profile it applies a suction to the water held in the soil above and water is withdrawn until an equilibrium state is reached. The equilibrium moisture content is dependent upon the applied suction. The suction is equivalent to the depth of the water table below the point in question. Work on cultivated soils by Gossage (1977) at the NCAE, fig 4, has shown that their strength changes wih suction. From fig 4 it can be seen that there is a greater increase in soil strength in the suction range 0 – 400 mm than in the range 400 – 700 mm. This substantiates the results given in fig 5 from Steinhardt and Trafford (1974) relating wheel sinkage to suction at plough sole depth. Both fig 4 and 5 illustrate the importance of lowering the moisture content below saturation to increase strength and reduce sinkage. The presence of shallow pans and smeared layers in the soil impede drainage thus decreasing the suction and soil strength. All compacted layers and pans must be eliminated to permit rapid water movement downwards to the drains.

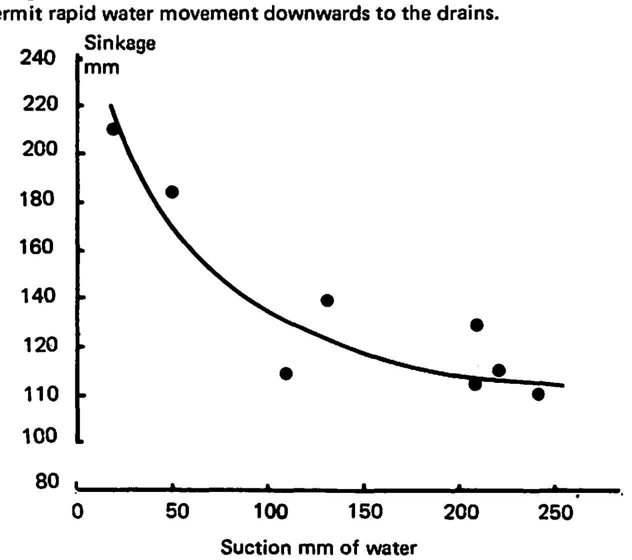


Fig 5 Tractor sinkage as a function of soil suction at plough sole depth. Redrawn from Steinhardt & Trafford (1974).

Under free draining conditions, drainage can only reduce the soil moisture content to a certain level depending upon the water table depth. This moisture level is termed field capacity. Whether or not a soil can be worked at this condition depends not only on the equipment being used but also on the moisture content at field capacity relative to the lower plastic limit. Where field capacity is below the lower plastic limit the soil can be worked quickly after rain; this is frequently the case with some coarse textured soils. Where field capacity is above the lower plastic limit, further drying through evaporation or transpiration is necessary before the work can commence. The more rapidly a soil reaches field capacity and the lower the field capacity moisture content the better.

Field capacity is not only influenced by the water table depth but also by the size distribution of the soil pores. Work at the NCAE comparing the properties of a range of tilths, from coarse to fine, prepared on Hanslope and Wicken series clay soils, has shown that coarse tilths of uniform depth produced by the mouldboard plough tend to have lower field capacity moisture contents than other tilths. A coarse tilth prepared by a chisel plough suffers from the disadvantage that the working depth and surface profile are irregular. During wet winters, water tends to concentrate in the low pockets left by the tine, giving high moisture contents and low shear strengths. Work can only commence on these tilths when the wettest areas have dried sufficiently. The field capacity moisture content of the undisturbed stubble condition on the above clays was lower than on all the cultivated profiles in wet years and higher in dry years. Provided that the undisturbed profiles were in a suitable density

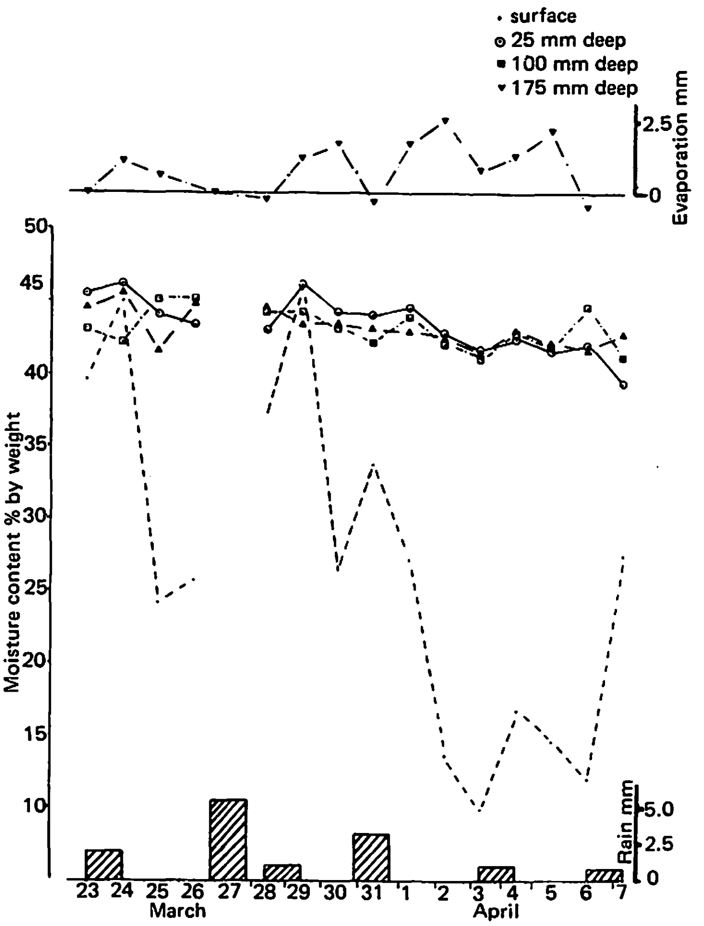


Fig 6(a) Effect of drying on moisture profile of undisturbed soil profile

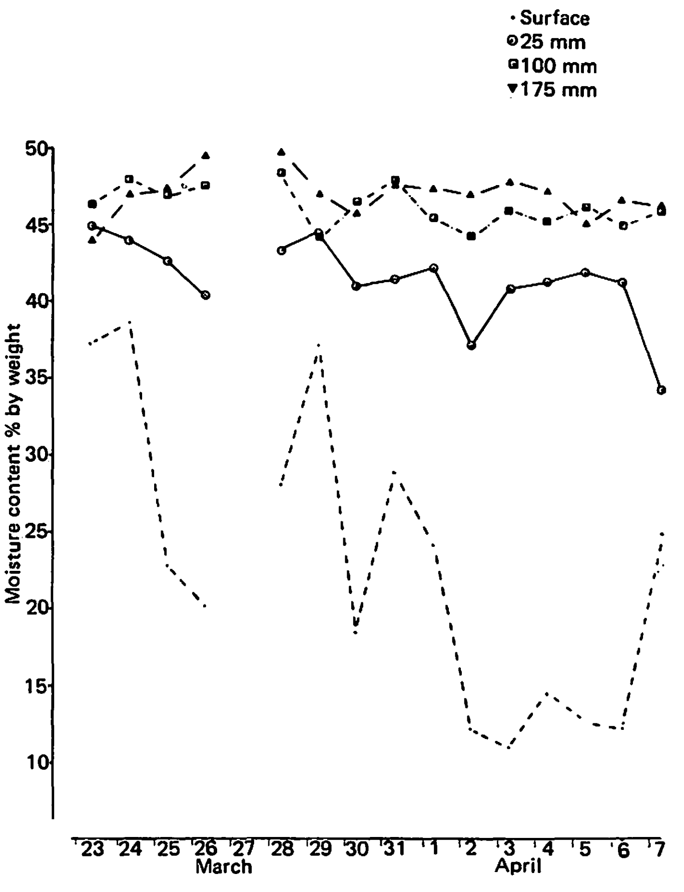


Fig 6(b) Effect of drying on moisture profile of cultivated tilth

condition for direct drilling and were dry on the surface, drilling could commence at higher moisture contents than in the cultivated areas. This was due to the greater strength resulting from the higher soil density.

Tractor sinkage on the undisturbed soil was one-third to one-quarter of that on the cultivated soil. The size of the clods in the cultivated tilth did not have any significant effect on the magnitude of the sinkage.

Where the field capacity moisture content is above the lower plastic limit work can only start after further moisture has been lost through evaporation and transpiration. Whilst transpiration can remove water from different parts of the profile, surface evaporation tends only to dry the surface layers. This is illustrated in fig 6 which shows the drying pattern in a Wicken series clay soil for undisturbed and cultivated tilth conditions, without vegative cover. The dry surface is clearly seen. Surface drying under given climatic conditions is influenced by the surface roughness, crop cover and rate of moisture rise from the deeper layers in the soil profile.

During the initial stages of drying, with high surface moisture contents, the evaporation loss from the soil surface can exceed that of an open water surface, due to increased turbulence and surface area. Once the dry surface crust is formed, further water loss is less than from the open water surface due to the restrictions to water movement within the soil profile itself. The relationship between the loss from the soil surface and an open water surface with time during drying is illustrated in fig 7, from wind tunnel drying experiments. A similar relationship was found by Ali (1977), given in fig 8, working on the same Wicken clay soil in the field. Iqbal and Warkentin (1972) showed that under zero radiation conditions smooth surfaces have a greater evaporative loss, whilst under radiant conditions rough surfaces lose water faster.

Once the dry surface crust has formed, the rate of water loss from depth in the profile on good drying days can be as low as 0.1 – 0.3 mm/day. These values were estimated on a basis of water diffusivity values of 450 mm^2/day. This very slow rate of water loss means that it is impractical for the farmer to wait for further drying and he must find ways of making maximum use of the stronger dry crust using improved traction and flotation devices.

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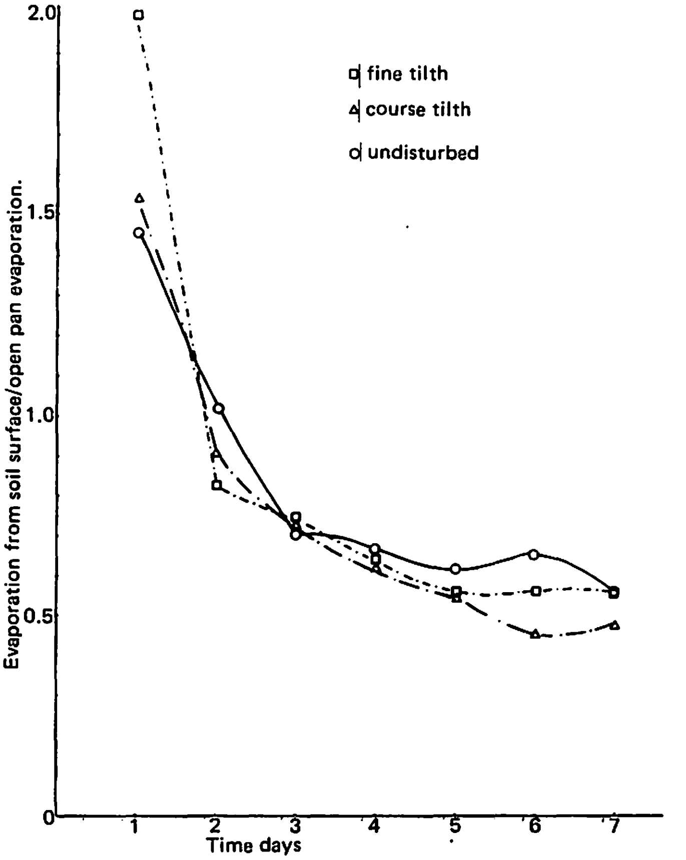
Fig 7 Relationship between evaporation from a soil surface/ open pan evaporation with time for a Wicken series soil.



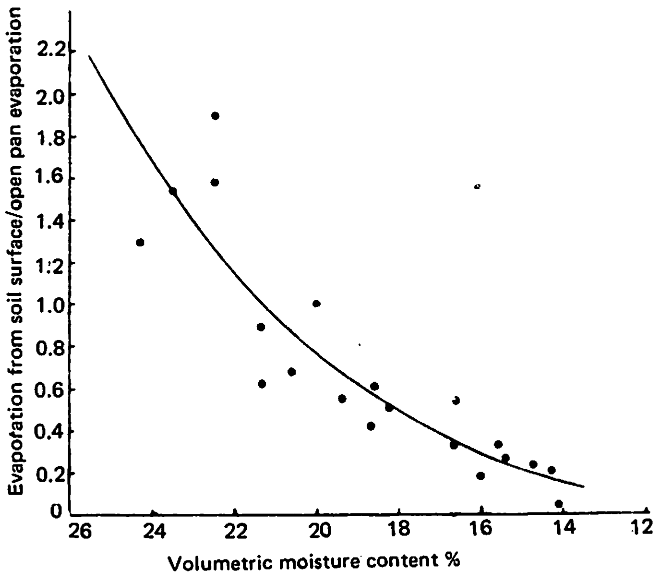


Fig 8 Relationships between evaporation from soil surface/open pan evaporation and soil moisture content for Wicken series soil from Ail (1977).

Practical implications

The ability of a soil to withstand the vertical and horizontal loads applied by a tractor or implement without excessive sinkage, wheel slip or structural damage is dependent upon its shear strength.

The shear strength increases as the soil dries out from saturation, the soil becoming more trafficable and the risk of structural damage decreasing. The soil approaches a working moisture content just below the lower plastic limit.

Undisturbed soils are stronger and can be run on, although not worked, at higher moisture contents than cultivated soils.

Good drainage is essential for early working but it can only remove a limited amount of water to bring the soil to field capacity. All impeding layers such as pans must be eliminated to permit rapid water movement downwards.

Where the field capacity moisture content is above the lower plastic limit, further drying through evaporation is necessary before work can commence. Evaporative drying on bare soils tends to form a dry surface crust, the soil below remaining near field capacity for a considerable time. Traction and flotation aids are therefore necessary to allow tractors to work most effectively with the stronger dry crust.

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Acknowledgement

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R J Godwin and G Spoor are from the National College of Agricultural Engineering, Silsoe.

Assessment of observed during

A J Thomasson

Summary

THE paper describes five soil properties, measured or estimated during soil surveys, which influence the duration of work days. A classification of soil structural condition is offered to take account of the combined effects and interactions among these properties. Possible benefits in terms of workability, soil structure and reliable crop production could arise from increasing the depth of impermeable soil, thus improving the water régime.

●

SOIL workability is difficult to define. It depends on time, both within and between years, and also on antecedent conditions such as the cropping sequence, drainage treatment and the standard of cultivations in previous years. The farmer tends to judge workability in terms of recent weather and there is no doubt that season-to-season differences are often greater than those between soil types. Nevertheless, we all recognise broad differences in workability between soils. Much chalk or sand land is workable at almost any time of the year, and a satisfactory seedbed can be produced easily. On much clay land timing is critical and in some seasons a tolerable seedbed can only be made with a great deal of effort. There are obviously situations between these two extremes. The main criteria of workability are then —

(a) the number of possible field work days, especially in the period March — April and September — October;
(b) the power and number of passes needed to produce a seedbed;
(c) the quality of the resulting seedbed.

Soil properties and workability

Soil properties are divided into three main groups in order of relative transience or permanence —

(a) Very transient (with reference to the plough-layer); water content, air-filled porosity and shear strength;
(b) less transient; bulk density, water retention (pore size distribution), plasticity, annual soil water regime, hydraulic characteristics; particularly for soil horizons below 0.3m;
(c) permanent — particle size distribution, organic matter content (for periods less than ten years), group (b) properties for horizons below about 0.5m.

In the field, group (a) properties are paramount for tactical decisions such as whether to plough, cultivate or drill today, tomorrow or next week. In fact, the practical test is likely to be the farmer's boot or a trial run across the field with the appropriate tackle. For strategic decisions such as the introduction of a new crop (or to discontinue one already grown), an extension of the cultivated area, installing new drainage or acquiring new machinery, the more permanent (b) and (c) properties become important.

Soil surveys identify mainly permanent properties in separating units on maps, but in recent years, both in the UK and in other countries, more attention has been given to the 'less transient' properties, seeking to establish associations between permanent properties, prevailing land use and water retention or hydraulic characteristics (Hall et al 1977, Hodgson 1974, Avery and Bascomb 1974).

The properties, measured or estimated during soil surveys, and most relevant to workability are —

(i) Retained water capacity, θ_v(0.05)%; defined as the volumetric water content of an undisturbed core of soil equilibrated at 0.05 bar (500 mm) suction. The Survey uses six classes for

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soil workability from properties soil surveys

this property (table 1). Most agricultural topsoils fall within the range of 25 to 50%. Retained water capacity is inversely related to shear strength and to bulk density. At larger values (greater than about 35%) the consistency of the soil is within the plastic range.

Table 1 Class limits for soil physical properties

Retained water capacity		*Air capacity (C_a) and Available water (A_v)*
$\theta_v(0.05)$	% volume	% volume
Very small	0 – 9.9	0 – 4.9
Small	10 – 19.9	5 – 9.9
Moderately small	20 – 29.9	10 – 14.9
Moderately large	30 – 39.9	15 – 19.9
Large	40 – 49.9	20+
Very large	50+	

Packing density, L_d	$g\ ml^{-1}$
Low	< 1.40
Medium	1.40 – 1.75
High	> 1.75

(ii) Air capacity, C_a%; defined as the volume of air-filled pores in a core equilibrated as above. Air capacity is inversely related to shear strength and to bulk density. Five classes are used (table 1). Alternative working definitions of retained water capacity and air capacity would be the water and air content, at field capacity, in well-drained soil.

(iii) Packing density, L_d, (Renger 1971); derived from bulk density (D_b) and clay content as:—

$$L_d = D_b + 0.009\ (\%\ \text{clay})\ g/ml$$

In this calculation bulk density should be adjusted to a fine earth basis by deducting the volume and mass of stones from the sample. Use of packing density avoids the need to stratify bulk density values according to particle size composition. Three classes are recognised (table 1). It is a fairly crude measurement, but easily replicated, and could be used as a quick, objective test of tilth quality in cultivation studies. It can also identify impermeable subsoil horizons.

(iv) Depth to an impermeable horizon; defined as having a horizontal, saturated hydraulic conductivity of less than 0.1m day^{-1}. As hydraulic conductivity is difficult to measure, a working approximation is an air capacity value of less than 5% in subsurface horizons. In soils finer than fine sandy loam, impermeable horizons normally have a high packing density. The presence of impermeable horizons within 0.6m depth usually reduces air capacity in the surface soil. In finer textured soils available water content is also less. These features are associated with increased bulk density (Hall et al 1977).

(v) Soil water regime. For workability, the important aspects of soil water regime are the depth to and duration of waterlogging. The Survey uses six wetness classes (table 2). In many places these classes can be inferred from gley morphology and other features of the soil profile, but for precise classification, monitoring of water-table levels is desirable (Robson and Thomasson, in press).

Table 2 Soil water regime; wetness classes (after Hodgson, 1974)

I	<30 days waterlogging within 70 cm depth
II	30 – 90 days waterlogging within 70 cm depth
III	90 – 180 days waterlogging with 70 cm depth
IV	>180 days waterlogging within 70 cm depth
V	>180 days waterlogging within 40 cm depth
VI	>335 days waterlogging within 40 cm depth

There are clear relationships between the depth to impermeable horizons, soil water regime and climate. Impermeable horizons will be saturated during the field capacity period as defined in MAFF Technical Bulletin 35 (1976). Where such horizons occur within 0.6m depth, the plough layer is unlikely to reach a suction greater than 0.05 bar by drainage alone. Consequently, bearing strength remains weak during winter and spring until water content at the surface is reduced (and suction increased) by direct evaporation. This effect is more marked in clayey than in sandy soils.

Table 3 Soil properties and workability

	Increased workability →		
Retained water capacity	Very large	→	Very small
Air capacity	Very small	→	Large
Packing density	High	→	Low
Impermeable horizons	Shallow	→	Deep
Wetness Class	VI	→	I

It is not easy to combine these properties into an overall assessment of workability. Table 3 simply shows the direction in which each property influences workability. For example a humose upland soil may have favourable values for all properties except soil water regime, but if the water-table is within 0.4m depth for more than half the year (180 days) and within 0.7m for all the year (Class V) the opportunities to cultivate are restricted. In Fen soils retained water capacity can be very large, but with a large air capacity, low packing density and a Class I water regime due to intensive drainage, the soil is easily workable.

Soil structural condition

To proceed further we must now consider the third aspect of workability — the quality of the resulting seedbed or, more precisely topsoil structural conditions. There are many subjective classifications of the visible macro-structure (Peerlkamp 1967, USDA 1951, Hodgson 1974). Ultimately, well-being of the plant itself is the test of soil structure, but seasonal changes in weather prevent the plant being used as the sole test. If we start from the simple concept that a well aerated soil with adequate reserves of soil moisture is desirable,

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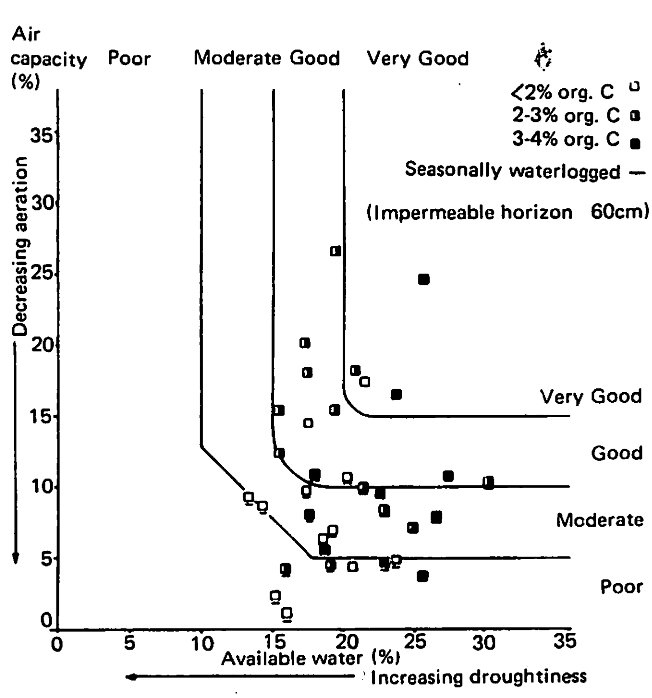
Fig 1 Classification of structural condition in clay loam and sandy clay loam topsoils.



then air capacity is a reasonable numerical index of aeration in the critical moist state. Water content at wilting point (15 bar suction) can be deducted from retained water capacity to give a plant available water content (A_v%). The two values combine (fig 1) to give a simple classification of soil structural quality, in which the class limits are somewhat arbitrary but may be improved by experience. The basis for the scheme is described in Hall et al (1977). Measured values for clay loam and sandy clay loam topsoils (18 to 35% clay and $<$ 20% sand) are plotted, with organic carbon levels, and an indication of the soil water regime. Wetness classes I and II are here considered as well drained, the remainder as seasonally waterlogged (mainly III and IV).

Samples were taken from consolidated arable seedbeds and temporary leys in lowland England. Old permanent pastures are generally excluded by their greater organic carbon content (above 4%). These and other results show that most particle size classes occur over a wide range of structural conditions. The range is in part related to water regime, part to organic carbon content and part other factors – presumably recent cropping and husbandry. However, it is noteworthy that the general mean of air capacity for arable sites is smaller than the mean for ley sites, indicating that the effect of disruption by ploughing is rather temporary.

The effects of waterlogging and organic carbon on structural condition were examined for an enlarged sample (table 4) from medium and heavy topsoils ($>$18% clay or $<$ 20% sand) of clayey, fine loamy or silty particle size groups (Avery 1973). Better surface structural conditions are here associated with naturally or artificially well drained soil profiles. Structure is moderate or poor at organic carbon contents below 2%, but little additional benefit is apparent above 3%.

Table 4 Topsoil structural condition in relation to soil water regime and organic carbon content for medium and heavy soils; per cent of samples in each class.

	Structural condition				
	Very good %	*Good* %	*Moderate* %	*Poor* %	*No of Samples*
Soil water regime					
Well drained (I & II)	19	51	21	9	43
Seasonally waterlogged (III + IV)	2	23	38	37	52
Organic carbon %					
<2	4	21	33	42	24
2 – 3	10	43	29	20	42
3 – 4	14	38	31	17	29

Discussion

Soil survey information of the type described here can be used in two ways. Classification of soil series in terms of workability has been attempted by Thomasson (1971), Jones (1975) and Jones (in press). This recognises and categorises existing limitations and the ways in which they are now dealt with. The second approach is to use soil physical measurements, made during surveys, to identify the main limitations to workability and where possible direct research and development work to better methods of removing those limitations.

The properties determining good structural conditions in topsoils or seedbeds overlap with those controlling workability – air capacity, packing density, soil water regime. In practical terms, it is usually easy to make a good seedbed if the seedbed of the preceding crop was also good. The converse that it is more difficult to make a good seedbed from one that was poor is also true. This interdependence suggests that measures to extend machinery work days should in the long term also improve seedbed quality. Reduction of clay content or a radical increase in organic matter content is difficult, but improvements in the water regime should be possible on most land with an annual rainfall below 750 mm (30 in). Pipe drainage, however, is only part of this process.

For large areas of the English lowlands, the presence of impermeable horizons at shallow depth – less than 60 cm – severely hinders the efficiency of drainage. New implements such as the 'wing' subsoiler and more timely use of the traditional mole plough may improve this situation.

The results for well drained soils presented in fig 1 and table 4 were mainly from profiles with *naturally* good drainage rather than *improved* drainage. However, it is likely that improvements in the water regime of naturally waterlogged soils can bring structural benefits. The evidence from table 4 suggests that the effect of good drainage on soil structure is equal to at least 1% of organic carbon (1.7% organic matter, or roughly 300 tonne/hectare of FYM at 70% water). To achieve real benefits, the improvements in soil water regime must virtually eliminate waterlogging from the upper 40 cm and severely curtail its duration within 70 cm depth. Few drainage systems on heavy land attain this level of control, though it is commonplace on fen and light land (Thomasson and Robson, in press).

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Field drainage and field work days: Results from a national experiment

A C Armstrong

Summary

RESULTS are presented from 60 experimental sites and show the number of days that drained sites were workable when undrained sites were not. The sites were all on surface water gley soils. A mean benefit of 25 days in the autumn and 27 days in the spring for the hydrologic year 1976–77, was closely related to the control of the water table achieved by drainage. There is an indication that on these soils, secondary drainage treatments (subsoiling or moling) gives increased benefits.

1 Introduction

IT has long been claimed that one of the major benefits of field drainage is the increased period during which the land is workable; that is, by lowering the watertable, the bearing strength of the soil is increased, and the soil's ability to withstand field operations is improved.

Evidence to support this view is, however, difficult to find, and this paper reports results from a set of co-ordinated experiments which demonstrate that such benefits do in fact accrue.

2 The experiment

As well as its advisory and statutory work the Land Drainage Service of ADAS, has an experimental and developmental role. Part of this experimental effort is currently involved in a series of co-ordinated experiments aimed at examining the soil water regime of the major soil series of England and Wales under both drained and undrained conditions. This experiment thus provides a bank of information both on the drainage status of the soils, and of the benefits derived from artificial drainage in these soils.

The experiment involves about 150 sites scattered throughout England and Wales. Each site consists of two "plots", one drained and one undrained, both of which ideally should be under identical management, in identical soils, and be in comparable topographic situations. Because of the operational difficulties involved the sites rarely meet all the ideal requirements. In particular, in the eastern half of the country one of the major difficulties has been the location of suitable undrained controls. All sites were located on surface water gley soils with low hydraulic conductivities, and have roughly similar natural drainage conditions. Sites with problems of arterial drainage were excluded from the analysis.

This study reports results from 60 of these sites, for which data is to hand for the hydrologic year July 1976 to June 1977.

At each site, at least four dipwells were installed on each plot. The mean watertable was recorded each week during the winter period, and, if possible, throughout the year. Usually, however, in an arable situation, the dipwells were removed in the spring to facilitate cultivations. At the same time as recording the watertable levels, the officers responsible for the site recorded the ground condition. This record of ground condition was made on a subjective scale, which, for all its imperfections, probably corresponds fairly closely to the assessment a farmer might be expected to make. The scale is reproduced as table 1, and for the purpose of this study the division between points 6 (damp and soft) and 7 (damp but firm) is taken as the boundary between trafficable and non-trafficable for arable cultivations.

Table 1 Scale of ground conditions

1	Snow
2	Hard frost
3	Very soft
4	Squelchy all over
5	Squelchy in parts
6	Damp and soft
7	Damp but firm
8	Dry on top
9	Baked hard

3 Individual results

Typically from each site, a record is available of the watertable, ground conditions, and rainfall, for a 'hydrologic year' running from summer to summer. However, there is a practical problem with leaving dipwells in an arable field during cultivations, and thus most of the records for such sites are for a shorter period during the winter. An example record is shown in fig 1 from a site in Gloucestershire, on the Denchworth series, where the drained land has drains with permeable fill at 60 m spacing with mole drainage. From this graph several features can be seen:—

1 It demonstrates the kind of water regime that should be considered normal, that is a low watertable in the summer, followed by a rising watertable in the autumn, a static, high watertable during the winter, and a declining watertable in the spring.

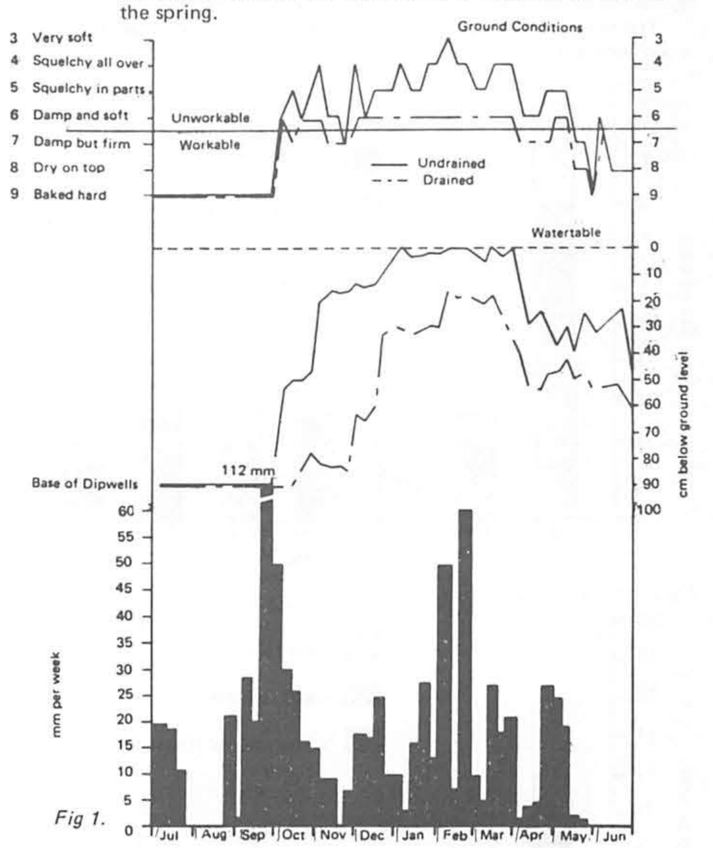

Fig 1.

2 Associated with the changes in the watertable are changes in the ground conditions, which are typically 'baked hard' in the summer, gradually getting softer during the autumn, and then again ameliorating in the spring.

3 On a site such as this one where the drainage is demonstrably effective, the watertables in the drained plot are consistently lower, and as a consequence ground conditions are generally better than in the undrained control. In addition several points specific to this graph can also be made.

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Paper presented at the Autumn National Conference (in association with South Eastern Branch) of the Institution of Agricultural Engineers, at Marks Tey Hotel, Marks Tey, Essex, on 11 October 1977.

4 The data refer to the winter of 1976–77, which was a particularly testing one for drainage. The rainfall of September and October was unusually intense, for between 1 September and 30 October a total of 302 mm of rain fell, of which 112 mm fell in one week alone. This deluge resulted in a very rapid rise of the watertable in the undrained plot, but a much slower rise in the drained plot. This site followed the general pattern, in that the soil did not wet up in the normal fashion, from the bottom upwards (ie with a rising watertable), but from the top downwards. The result was that the surface layers of both plots rapidly became saturated and hence unworkable, even though the soil profiles were dry at depth, and the watertables correspondingly low.

5 Nevertheless, once the initial wetting was over, there was a period in the autumn when the drained plot was workable and the undrained plot was not. Similarly, in the spring the drained plot reached a workable state 40 days earlier than the undrained plot.

4 National results

This discussion of a single site leads to a conceptual model that can be used to report data from the national experiment. The hydrologic year is divided into two areas of interest: the autumn when the soil is in a wetting phase, defined arbitrarily as the period 1 September to 31 December, and the spring, when the soil is in a drying out phase, defined as lasting from 1 March to 31 May. Separating these two periods are the winter months of January and February, during which cultivations are not normally carried out, and during which the question of trafficability is less important. The summer period, from 1 June to 30 August, is similarly discounted from the analysis.

During each of these two periods of interest, two measurements of drainage benefit can be derived. Firstly, the increase in the number of days the drained plot is workable in comparison with the undrained plot, which is a direct measurement of the workability increase. Secondly, the hydrologic effect of drainage can be described by the mean watertable levels of both plots for these fields.

The results of the days of benefit are shown in fig 2 and 3. The mean increase in workability in autumn is 25 days, and for spring, 27 days. The scatter is, however, very high, with some sites showing extremely high benefits, and some only small, or no benefit at all. The large number of sites with no benefit in the autumn can, in part, be explained by the abnormal wetting pattern observed on many sites, with the surface layers becoming rapidly saturated and hence unworkable while the subsoils remained relatively dry.

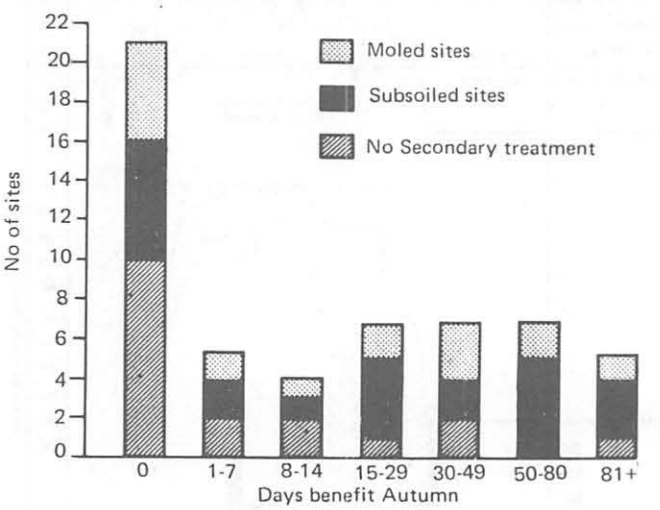
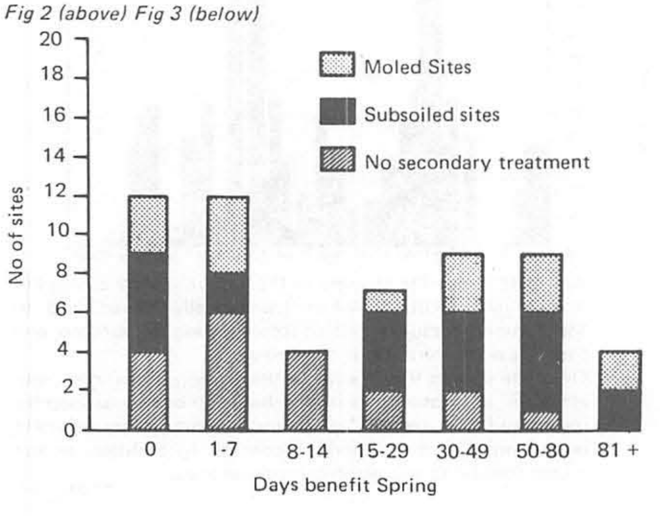


Fig 2 (above) Fig 3 (below)



These diagrams have been split to show the contributions of moled sites, subsoiled sites, and sites with no secondary treatments. Statistical analysis indicates that the proportion of moled sites in each of the benefit categories is roughly equal, but that a large proportion of the subsoiled sites show high benefits, and that conversely sites without secondary treatments show a high proportion with low drainage benefits. This conclusion is in agreement with recent experimental work which indicates that some form of secondary treatment is necessary for the effective drainage of clay soils (Trafford & Massey 1975).

An analysis of the watertable records shows that these improvements in soil workability were roughly correlated with the hydrologic data. An overall correlation of 0.43, between the number of benefit days and the difference in mean watertable levels between the two plots, was observed, which is greater than could be expected by chance. Further analysis of this data showed that a large proportion of sites without secondary treatment showed little or no control of the watertable.

5 Discussion

These results clearly show a great range of responses to drainage. Some sites show enormous benefits, in excess of 80 days, while others show no benefit whatsoever, and this requires some comment.

Firstly, the data reported here comes from a vast range of sites, many of which involve two plots separated by some distance, and thus of only general comparability. Thus we can expect from an experiment of this nature data that will show very considerable spreads around their mean values.

Secondly, the hydrologic year 1976–77 was (like all others) in some respects, atypical. In particular the very wet autumn following a drought summer resulted in an abnormal wetting-up of the soil. In many cases soils seemed to be wetting-up from above, so that although watertables were still low, surface horizons were soft and the ground not cultivable. The situation is observable in the example site shown in fig 1.

Thirdly, it must be admitted that there are a certain number of sites where the drainage has not appeared to be successful. Some of these may be explained by the presence of drains in the 'control' plot which were not located by the original site survey. Nevertheless, some sites do show drainage failure, and reasons must be put forward for these. In the case of the drains alone scheme, it could be argued that such drainage systems are likely to be only marginally effective in clays of very low hydraulic conductivity, and in the case of secondary treatments there is every possibility that the subsoiled or moled channels can have collapsed or were never formed in the first place. Nevertheless, although we can offer some explanations for the apparent failure of some drainage schemes, these 'explanations' are not cause for complacency, and the relevant sites will need examination in detail.

These results, however, refer to only one year, and need not be typical. The previous year, 1975–76, failed to show any drainage benefits in many areas, for instance, simply because the soil remained below field capacity throughout the winter. Indeed the autumn of 1976 proved to be a particularly testing time for drainage systems, with the heavy rains falling on a soil which had been baked by the previous drought.

6 Conclusions

This study has shown how results from a national soil water regime study have been used to derive information about the influence of land drainage on workability. Although the data derived is subjective and subject to a considerable amount of scatter, it is consistent throughout 60 sites in showing, on the average, an increase in soil workability. Defining the benefit of drainage as the number of days the soil is workable on the drained plots but unworkable on the undrained, the mean effect of drainage is 25 days in the autumn and 27 days in the spring, for the year 1976–77. The total increase of 52 days during which the land is workable must have a significant effect both on farm management, and total yields derived.

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Work days from weather data

C V Smith

Summary

METHODS for estimating the farm work days available for operations involving soil movement have been examined. Successive approximations may be obtained from an informed guess, past experience, experimentation, and experimentation leading to objective generalised statements requiring simple information on soil type and access to representative weather records for the site of interest.

The transformation from work day criteria based on rain days, to criteria based on soil moisture (and by inference on the physical properties of the soil) enables a range of field operations (spring planting, summer and autumn drainage, autumn root harvest) to be discussed in terms of a single weather derived variable, the soil moisture deficit.

1 Introduction

1.1 My brief has been to indicate the methods used to arrive at work days predictions and to comment on their limitations.

In placing this topic with a meteorologist there is the implicit assumption that farm operations involving soil movement are both weather dependent and weather sensitive.

Quite different weather criteria are to be associated with field work on the arable farm in the spring and autumn periods.

In the spring, during working down and drilling, there is a concern for the state of soil and the seed bed. The farmer's decisions are sensitive to gradations of the soil state and the soil structure, and associations between weather and work days can be developed.

In the autumn, however, if the problem is one of lifting and clearing a root crop, the job remains one affected by the weather; but in the limit, decisions on work rest not on fine gradations of the soil status, but simply on whether machinery can move through the mud. The operation is certainly weather dependent but scarcely weather sensitive. Meteorological comment is possible, in that we may monitor the build up of soil moisture and the approach of difficult working conditions; but the development of associations between weather variables and work days is scarcely to be contemplated. Almost each and every day is a potential work day and considerations other than weather drive the operation along.

1.2 Before the meteorologist can make a sensible comment on a farm problem he has to understand what is involved, he has to convert the farm problem to physical or biological processes which interact with weather inputs and weather processes, and he has to be aware of, and even identify with, the realities of life on the farm.

However, the realities of life do not always allow an optimum solution, and faced with a problem that requires a fairly immediate solution without the necessary background information, both the farmer and his adviser are likely to react in broadly similar ways. Successive approximations to a satisfactory answer might be obtained from

- an informed guess
- past experience
- experimentation
- generalisation from experiment.

Because of their different backgrounds, and because people tend to try first procedures that have worked for them in the past, the outcome from the practicing farmer and the meteorologist will be different. The most fruitful outcome is likely to be that from a collaboration which combines the expertise of both.

We examine and comment on the approaches to the problem of estimating the seasonal availability of field work days.

2 The informed guess

The individual farmer is unlikely to carry a figure for work days in the spring around in his head. However, he will know the number and rating of his tractors and the intensity of effort needed to get through his acreage in the typical season. And if he recalls a difficult season in the recent past, he may uprate his power requirements when next he buys a new tractor.

The figure our working farmer gives is certainly going to be of the right order of magnitude, but subjective, biased to the recent past and difficult to generalise.

The approach of the meteorologist at this stage will be to obtain, by discussion, a superficial knowledge of the soil moving problem, and then to guess possible threshold values of likely relevant weather variables.

Reference to past weather records close to the site of interest will enable a count of days estimated to be suitable for work and identified by some arbitrary criteria.

The result, hopefully, should be of the right order of magnitude; it will be subjective, but it will not be biased by personal memory and will be capable of generalisation.

3 Past experience

The working farmer now offers more than an off the cuff reply. Past experience may even imply a reference to farm diaries and a count of days from records made basically for other purposes.

Questions which come to mind now must include the effects of personal memory and bias and the representativeness of individual experience. In addition there are the difficulties that experience takes time to acquire, that the method of transfer to other sites, soil types and climatic regions is not obvious, and that the subtleties to be associated with seasonal variations in weather, or with climate trends, are not readily disentangled.

The background to the "Gang-Work Day" estimates which were applied in the east of England and elsewhere would appear to be the data extracted by the Provincial Economists from surveys devised essentially for other purposes eg the annual *Farm Management Survey* or enterprise cost studies.

The important point to recall here is that the basic records indicated hours of men and machinery inputs, and not what the farmer should have been doing or might have wanted to do. The distinct possibility of a mismatch between the "weather windows" actually available and the timeliness of the actual operation is there, but appears to have been ignored (Duckham 1963). What we end with is an estimate of the average number of field work days taken up, but not necessarily the total of such days available, on the average farm, in the average season.

The approach of the meteorologist at this stage would, in many situations, include the use of weather dependent variables not normally directly observed or recorded. With the key variables identified in this instance as soil moisture in the surface layers, together with soil type and soil structure in the upper layers, the meteorologist might from his information on the rainfall input, the surface drying by wind and sun, from an understanding of water movement down the soil profile etc attempt to develop more relevant weather dependent indices, threshold values of which would equate with probable work days.

The result is a series of estimates or numbers which have to be validated (or normalised), that have to be checked against what actually happens on the farm, if this is at all possible.

Our previous comments on the shortcomings of the meteorologists' method still apply to this more sophisticated approach; the requirement for a "ground truth" comparison leads us fairly naturally into experimentation or observational study.

4 Experimentation

The individual farmer in any one season may deliberately set out to improve his understanding and experience of what factors constrain his field operations, but is unlikely to have the time or facility to measure and analyse the associated weather variables. Our farmer is no stranger to innovation or to a thoughtful trial and error approach.

However, the outcome of work days for the individual farmer in any one season might be seen as representing a single set of circumstances and a single point on the family of lines or curves representing an association between weather variables, work time and soil type.

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Experimentation requires observation of response to a set of circumstances that are varied. The farm adviser, by noting the outcome for a large number of farmers, each with his own local weather and soil type in effect, in a season or two, is likely to cover a sufficient range of circumstances for the association between weather and work days to be sketched in.

This in fact was the procedure adopted in the East Midland Region. Farmers recorded the days on which they worked, soil scientists visited each to identify soil types, meteorologists recorded the local weather and drew all the resultant information together. The result was a set of statements based on observed weather variables alone, that effectively reproduced the farmers' decisions, both individually and collectively, that a given day was to be regarded as suitable, or otherwise, for field working.

The advantage of such an approach is that

- it begins with the "ground truth" and is based on reality
- it draws on and distills the lifetime experience of the individual farmer
- the inclusion of a large number of farmers smooths out the personal bias
- it presents the basis for a generalisation and a transfer of experience to other sites and to other climate zones (given appropriate weather data).

One aim of experimentation must be the prediction of the outcome in later trials. The weather statements on work days were in fact tested in this way and found satisfactory, on different farms and with different farmers.

5 Generalisation

5.1 We come finally to the crux of our topic and it is as well to review essentials.

From short period field studies we develop numerical associations between values of weather variables (or weather derived variables) and what is by consensus a day suitable for field working operations, on each of a spread of soil types.

We check the association in a further independent test.

The final stage is to take the relationship and to reinterpret long period weather records as records now of farm work days. In doing this we enable a ready transfer to any site for which we have weather records, we minimise personal bias and reliance on personal memory, and have made the process as objective as possible. The further generalisation problems for farm work days are in this way transformed to the more familiar ones of manipulating, interpolating and synthesising weather data and weather records.

5.2 The statistical model

For the spring work day relationship, there was the development of criteria which indicate that after an initial dry spell, rainfall on any one day above certain thresholds inhibits field work for so many days afterwards.

This approach is purely statistical and the relationship, as such, offers no causative link between rainfall and its effect; the relationship employs only a directly obtained weather variable namely rainfall.

5.3 The physical model

The decision on whether to work or not at an operation involving soil movement obviously turns on the physical state of the soil, and whether the soil crumbles on being stressed or sheared, whether it sticks or smears, or whether it compacts irreversibly (in the short term), or even, in the limit whether it will support the (machinery) load placed on it.

We can in fact move towards a weather derived variable of more direct interest to the soil scientist and farm engineer if we present the association between weather and work days, not in terms of rain days but in terms of soil moisture status. The simplest variable for us is soil moisture deficit.

The advantage now lies in that differing thresholds of soil moisture deficit may then be employed to describe soil suitability for a range of quite different field operations viz spring cultivation, drainage operations, autumn harvesting and ploughing.

Our generalisation is in this way given a further dimension if a unifying physical variable derivable from weather records, is employed.

6 Some results

6.1 Spring work days

The work day criteria based on rainfall have been made available elsewhere (Smith 1968) and will not be reproduced here.

If we transform the criteria to those based on soil moisture deficit in the top most soil layer they read as follows:—

a *First start to work*
For a Heavy soil, the threshold is a soil Moisture Deficit of 3.0 mm
For a Medium soil, the threshold is a soil Moisture Deficit of 2.0 mm
For a Light soil, the threshold is a soil Moisture Deficit of 1.0 mm

b *Temporary end to work by wet weather*
The data suggest that for all soils, the top most soil layers achieve a loss of *excess* soil moisture by downward percolation, and by evapotranspiration. A run of work days on a heavy soil is brought to an end by a rainfall input (in one day) which is greater than the sum of twice the potential evapotranspiration loss on that day plus the daily percolation loss of 3.0 mm. A run of work days on medium and light soils is brought to an end by a rainfall input (in one day) which is greater than the sum of twice the potential evapotranspiration loss on that day plus the daily percolation loss of 4.5 mm.

c *Start to work after temporary interruption by wet weather*
Work begins again, after being interrupted by rain, when sufficient days have elapsed to remove the recent rainfall excess, by evapotranspiration and percolation.

In arriving at these criteria, the estimated potential evapotranspiration has been inferred from a monthly value, some minimum value being allowed on each day (including dull days) and the remaining monthly loss being partitioned according to the count of daily sunshine hours.

The results of applying these criteria are shown in table I in tabular form for representative sites in some counties.

Table 1 Upper limit to machinery work days (mid-February to April) inferred from soil moisture deficit estimates

County	*Work days 2 years in 10*			*Work days 5 years in 10*		
	Soil			*Soil*		
	Heavy	*Medium*	*Light*	*Heavy*	*Medium*	*Light*
Essex	35	45	50	45	55	60
Beds	25	40	55	40	50	60
Cambs	25	45	55	50	55	60
Suffolk	25	45	55	45	55	60
Oxon	30	45	55	40	55	60
Wilts	25	40	50	35	50	55
Avon	30	40	45	40	50	55
W Mids	30	40	55	40	50	60
Devon	25	40	45	35	45	50
Salop	20	40	55	40	50	60
Cheshire	15	45	55	35	50	60
Lancs	15	40	55	30	50	55
Notts	15	35	50	35	45	55
Lincs	10	20	45	30	45	55

6.2 Moling

In looking at field drainage problems one automatically restricts attention to the heavier soils; in this analysis, problems arising from local topography and geology and high water tables are of necessity excluded.

We may use weather data to operate a soil moisture budget between rainfall inputs and percolation and evapotranspiration losses; we may follow both the build up of the deficit soil profile in the normal growing season, and the return to field capacity in the normal winter.

The assumptions involved are:—

- the maximum soil moisture available to crops in the various soil horizons
- the partition of the evapotranspiration loss down the soil profile
- the partition of rainfall down the soil profile in the rewetting process.

The moisture held in a given soil horizon is assumed to be indicative of its plasticity, and the extent to which the soil will flow together again into a channel drawn by a drainage tool.

We may examine the field results of moling operations in conjunction with the associated soil moisture profiles and in particular the soil moisture in the horizon at which the moling operation takes place. Some results are shown in table II.

The inference is clear.

Table II Maximum available soil moisture, soil moisture in the profile at the time of moling, and moling success

Crop Cereals	year	*Maximum water available in layer*															
		0/ 10 cm	*10/ 20*	*20/ 30*	*30/ 40*	*40/ 50*	*50/ 60*	*60/ 70*	*70/ 80*	*80/ 90*	*90/ 100*	*100/ 110*	*110/ 120*	*120/ 130*	*130/ 140*	*140/ 150*	
		20 mm	18	12	[10]	10	[10]	10	10	10	5	5	5	2	2	1	
Site		*Water in profile at time of operation*															*Success*
Drayton	1971	0	17	12	10	5.8	[5.4]	5.4	5.4	7.3	5	5	5	2	2	1	Yes
Drayton	1970	10.7	11.4	6.9	6.9	6.9	[6.9]	6.9	6.9	6.9	5	5	5	2	2	1	Yes
Drayton	1969	20	18	12	10	10	[10]	10	10	10	5	5	5	2	2	1	No
Layer Breton	1971	0	2.6	2.6	2.6	2.6	[2.6]	2.6	2.6	2.6	2.6	2.6	2.6	1.4	1.4	.7	Yes
Layer Breton	1970	20	18	12	10	10	[10]	10	10	10	5	5	5	2	2	1	No
Kettering	1969	20	18	7.8	6.3	6.3	[6.3]	6.3	6.3	6.3	5	5	5	2	2	1	Yes
Kettering	1969	20	18	12	10	10	[10]	6.6	6.6	6.6	5	5	5	2	2	1	No
Crop Grass		*Maximum water available in layer*															
		20 mm	18	12	10	10	10	10	10	5	2	2	1	–	–	–	
Site																	*Success*
Wilburton	1970	0	0	0	0	0	[0]	1.6	2.8	2.8	2	2	1				Yes
Melton Mowbray	1964	0	0	0	1.6	5.1	[5.1]	5.1	5	5	2	2	1				Yes
Cefn Coch	1971	0	0	0	[0]	0	0	0	.7	5	2	2	1				Yes
Langabeare	1964	0	0	0	0	2.4	[5.5]	10	10	5	2	2	1				Yes
East Worlington	1965	20	18	12	10	10	[10]	10	10	5	2	2	1				No

[ ] *denotes level of operation*

Failure is likely if the available water in the soil layer at which moling takes place is at, or close to, the maximum available in that layer (to crops) at field capacity.

The need and the opportunity for meteorological comment is obvious, but there are limitations in fact to what we may say.

One reason for this is the nature of the soil with which we deal. There is ample, consistent evidence from neutron probe data, from lysimeters and from tensiometers of the behaviour of the soil/crop system under the drying phase of the soil moisture hysteresis cycle. There is commonly a progressive drying with depth; once the top soil has given up its available moisture, successive layers are exhausted in turn. On heavy (clay) soil, the two arms of the hysteresis cycle are, in the limit, to be associated with significant changes in structure and volume, with shrinking and cracking on the one hand and swelling on moisture uptake, on the other.

For the lighter lands, which do not show such hysteresis effects to any great degree, the conventional model, on rewetting is of the progressive movement downwards of the wetting front, as rainfall applied to the surface brings successive horizons back to field capacity.

It would seem that such a simple model may not be valid for the heavier lands when subject to a substantial moisture deficit. There is evidence to suggest that in situations such as these, and particularly when rainfall is heavy, there may be some wetting down the complete soil profile before the topmost layers are brought back to field capacity; cracks may even lead surface water down quickly and give rise to wetting from below.

The implication is that whilst the meteorologist may be able to indicate a time to the start of successful field drainage (moling) operations as soil moisture deficits open up gradually through crop water extraction, the end to successful operations may be sudden rather than gradual and to that extent capricious and unpredictable, depending as it does on the local arrival of rainfall in excess of a certain amount and a certain rate of fall. This gives rise to uncertainty both in the individual season and in any longer term statistics needed for forward planning.

6.3 Autumn field work

Other relationships between the likely success of drainage operations and the total soil moisture deficit in the profile (as distinct from the deficit in the horizon of operation) are suggested by Smith and Trafford (1975).

The further important information included in their publication (*MAFF Technical Bulletin 34*) is a method to arrive at the statistics of the date of return to field capacity for any site in England and Wales.

These statistics, based on long term weather records, set for planning purposes, the target date for the completion of tasks which require a soil to be at less than field capacity for their success, or to avoid long term, structural damage.

7 Future needs

7.1 Updating

If our weather statistics are routinely updated, any gradual climate trends or small changes in the variability of seasons are automatically incorporated.

Scenarios which take in an abrupt shift to less favourable conditions and for example an increasing probability of a succession of seasons with poor field working conditions could be accommodated by the progressive exclusion of favourable years in the recent past from our planning statistics.

The positive prediction of a succession of poor working seasons, as distinct from studying their agricultural implication, is not a matter on which the meteorologist or indeed anyone else can at this time offer useful advice.

One has to point out that the analysis of the long period records of rainfall for this country, which take us back to the 1700's, do not in fact support the view of major and obvious changes or trends in the rainfall regime of this country; the analogue of each season can be found in the past and the risk of last year's drought was implicit in those statistics.

7.2 Changes in technology

The wide spread adoption of heavier machines, of minimum cultivation techniques, of pre-germination and fluid drilling would each require that the weather criteria for field work should be determined again ab initio.

7.3 Operational advice

The weekly issue by the Meteorological Office of soil moisture deficit advice, in map form, for conventional ground cover, is a source of information not to be neglected. It will still be capable of improvement in detail. The bulletin does not involve any element of forecasting but is based on measured rainfall etc.

Useful help would be given if quantitative rainfall forecasts could be given for the next few days. This is a step toward which we are working.

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Ground drive equipment and aids to extend trafficability limits and minimise soil structural damage

D Gee-Clough

Summary

THE effects of various design and operating parameters on the tractive performance of tractor drive tyres are described. The comparative performance of 2-wheel drive, 4-wheel drive and track-laying tractors and the advantages of fitting larger than standard drive tyres on tractors are discussed.

A method for modelling the performance of a tractor-plough combination is described and the comparative performance of different traction aids discussed. The influence of tractive devices on soil compaction is described.

Factors affecting tractor drive tyre performance

AN extensive programme of work has been undertaken at NIAE since 1971 to measure the effects of various design and operating parameters on the tractive performance of tractor drive tyres in as many different field conditions as possible.

From this work it was established that, for tyres having an open-centre R1 tread type, small differences in tread pattern have a negligible effect on tractive performance (Dwyer *et al* 1975). The small differences in tread pattern mentioned here are typical of those likely to occur on similar sized tyres from different manufacturers.

The effect of lug height on tyre performance has been the subject of considerable debate over the years. Advocates of high lugs argue that they are necessary to provide traction in poor field conditions and opponents argue that increasing lug height decreases efficiency without affecting pull. It was decided to study this effect in some detail in an attempt to settle this controversy. Consequently five 13.6 x 38 tyres with lug heights from 0 to 75 mm were tested in 40 different fields over a period of three years. Overall it was found that when the lug height was increased beyond 20 mm, tractive performance decreased. When the results from fields in which traction conditions were poor were analysed separately, it was found that there was no difference in performance between the tyre with 20 mm lugs and those with higher lugs. Thus although a lug is needed to break through soft surface layers, a very aggressive lug is not needed and will in general lead to a decrease in performance (Gee-Clough *et al* 1976).

Manufacture of radial-ply tyres has recently been started by some British tyre manufacturers and it is therefore an opportune moment to discuss some tests, completed about a year ago, on the relative tractive performance of radial and cross-ply drive tyres. The performance of two 13.6 x 38 radial-ply tyres and a cross-ply tyre of the same size was measured over a three-year period. It was found that when the inflation pressure was low (80 kPa or 11 lb/in^2) the radials gave an average 5–8% increase in pull at 20% slip but the maximum tractive efficiency was the same for all three tyres. When the inflation pressure was increased to 160 kPa there was no difference in performance between any of the tyres (Gee-Clough et al 1976). It seems likely therefore that radial-ply tyres obtain their superior performance due to increased side-wall flexibility and that this effect is nullified as inflation pressure is increased. Manufacturers claim that radial-ply tyres have considerably better wear properties than cross-ply tyres; however we have carried out no tyre wear tests at NIAE and cannot therefore comment on this claim.

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Tyre aspect ratio (section height/section width) is another parameter which will obviously affect sidewall stiffness. However the range of aspect ratios available in commercial tyres is quite small. When a conventional 13.6 x 38 tyre having an aspect ratio of 0.75 was tested against a similar tyre having an aspect ratio of 0.69 no difference was found in their tractive performance. When the inflation pressure in the low aspect ratio tyre was decreased for the same load however (which the manufacturer claimed was safe) then it performed slightly better than the other tyre (McAllister *et al* 1976).

Forward speed is a parameter which one would expect to affect tractive performance since many soils are strain-rate sensitive. Unfortunately the maximum forward speed for testing in the NIAE Single Wheel Tester is 6.4 km/h (4 miles/h). Even so an increase in performance was measured when the same tyre was tested at 6.4 km/h as against 3.2 km/h and further increases in forward speed may result in increases in tractive performance which are of practical significance (Gee-Clough et al 1977).

Mouldboard ploughing with wheeled tractors is normally carried out in the UK with the furrow-side wheels of the tractor running in the furrow bottom. Traction conditions in the furrow bottom can often be very different from those on the surface of the field and this will obviously affect performance. The tractive performance of a 13.6 x 38 and a 16.9 x 34 tyre was measured when running in a 356 mm (14 in) furrow and on the surface of the same field. Field conditions varied considerably during the two year test period and it was found that this affected the results. When field conditions were poor (soil wet and soft or considerable surface trash present) or average, both tyres gave an average 13% increase in pull at 20% slip when running in the furrow bottom with no loss in maximum efficiency. When field conditions were good however both tyres gave the same pull in the furrow bottom as on the field surface but maximum tractive efficiency in the furrow decreased by 10% for the 13.6 x 38 and by 15% for the 16.9 x 34 tyre (Gee-Clough et al 1976).

A similar local change in traction conditions can be found when a tyre runs in a rut previously made by another tyre. When this effect was tested it was found that a 13.6 x 38 tyre gave 7% higher pull and 5% higher maximum efficiency when compared to running on the undisturbed field surface (Dwyer *et al* 1975).

On examination of the overall results of these experiments it was concluded that the main parameters affecting the performance of tractor drive tyres are tyre size, load, inflation pressure and local changes in traction conditions such as those found when running in the furrow bottom. A large increase in forward speed could possibly lead to significant increases in tractive performance but this has yet to be confirmed. Radial-ply carcass construction does lead to improved tractive performance but not by as much as is sometimes claimed by its supporters. Data on the relative wear resistance of radial and cross-ply tyres would be very useful. Aggressive lugs do not seem to be required in typical British field conditions and small differences in tread pattern between tyres having an open centre R1 tread type make no difference to performance.

Two-wheel drive, four-wheel drive and tracklaying tractors and the effects of fitting larger drive tyres

During the period 1967–69 field tests were conducted at NIAE to compare the performance of a 52 kW (70 hp) tracklayer to a 67 kW (90 hp) two-wheel drive tractor and 67 kW four-wheel drive tractor with equal sized wheels. The reason for choosing these sizes was that at that time these tractors all had approximately the same purchase price in the UK.

Overall it was found that the mean work rate when ploughing of

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the two-wheel drive tractor and the tracklayer was almost identical. The four-wheel drive tractor produced an average 14% greater output than the other two tractors. However, field conditions were found to have a large influence on the comparative performance and on firm dry surfaces the outputs of the two and four-wheel drive tractors were the same. This implies, as expected, that under these conditions output is simply a function of available power.

Although the overall performance of the tracklayer was comparable to that of the two-wheel drive tractor, in heavy field conditions its output was equal to that of the four-wheel drive machine despite the large difference in available power (Osborne 1971).

Clearly a tracklayer is a superior machine for performing field operations which require heavy draught loads. Because of the low mean ground pressure exerted by tracklayers they can also be expected to perform in field conditions which wheeled tractors would have great difficulty coping with. However the choice of ground drive equipment for a tractor is rarely a simple matter, the relatively poor field performance of wheeled tractors having to be gauged against their main advantages which are their ability to travel on highways and their great versatility.

A simple method of improving the field performance of two-wheel drive tractors is to fit larger drive tyres. Two 49 kW (66 hp) two-wheel drive tractors, one fitted with 18.4 x 30 drive tyres and the other with 13.6 x 38 tyres, were tested against each other when ploughing. The 18.4 x 30 tyres are approximately the same diameter but about 35% wider than the 13.6 x 38 tyres. 13.6 x 38 tyres are widely used on this size of tractor and may in fact be regarded as the "standard" size. The results of the tests are shown in table 1.

Table 1 Comparative performance of two 49 kW (66 hp) tractors with different sized drive tyres when ploughing

	Gear	*Drive tyre size*		*Comparative performance index of 18.4 x 30 tyres (13.6x38 tyres = 100)*
		18.4 x 30 at 75 kPa inflation pressure	*13.6 x 38 at 150 kPa inflation pressure*	
Max power delivered (kW)	3	26.5	24.1	110
	4	33.2	31.3	106
	5	36.6	34.5	106
max power / max pto power (%)	3	54.1	49.2	110
	4	67.8	63.9	106
	5	74.7	70.4	106
Pull at max power (kN)	3	21.0	18.4	114
	4	19.7	18.4	107
	5	18.6	17.1	109

The plough used cut a 356 mm (14 in) wide furrow; consequently the 18.4 x 30 tyres overlapped the furrow slightly whereas the 13.6 x 38 tyres did not. Even so table 1 indicates that the tractor fitted with 18.4 x 30 tyres delivered appreciably more power and gave a higher pull at maximum power than did the tractor with 13.6 x 38 tyres. Considering the field conditions during the tests it was estimated from the *Handbook of Agricultural Tyre Performance* (Dwyer *et al* 1976) that a maximum tractive efficiency of 78% should have been possible with the coefficient of traction at max. efficiency being 0.41. Table 1 shows that neither tractor was operating at its optimum efficiency point during the tests. Table 2 shows the rear axle load and tyre inflation pressure required to make the tractors operate at the optimum efficiency point. Neither tyre size would have been able to carry the ballast required to produce optimum efficiency in 3rd gear and the 13.6 x 38 tyres could not have carried the additional ballast required in 4th or 5th gears either (Gee-Clough *et al* 1976). The value of fitting larger drive tyres in poor traction conditions will be referred to later in this paper.

Table 2 Optimum ballasting and tyre inflation pressures required for a 49 kW (66 hp) tractor

Gear	*Avg speed at max efficiency (m/sec)*	*Pull req'd to use available power at this speed (kN)*	*Rear axle load req'd to produce this pull (kN)*	*Tyre inflation pressure req'd (kPa)*	
				18.4 x 30 tyres	*13.6 x 38 tyres*
3	1.3	29.4	71.7	NP	NP
4	1.7	22.5	54.9	130	NP
5	2.0	19.1	46.6	100	NP

NP = not possible — load required is higher than the maximum allowable

Modelling tractor-plough performance

It is clearly important that tractor-implement performance be mathematically modelled so that trafficability limits can be predicted and optimum combinations of tractor power, weight, speed and load determined.

With this end in mind the results from the Single Wheel Tester were analysed to look for a relationship between the main traction parameters and the tyre mobility number. The tyre mobility number (M) is defined as:

$$M = \frac{Cbd}{W}\left(\frac{1}{1+\frac{b}{2d}}\right)\sqrt{\frac{\delta}{h}} \quad \ldots\ldots (1)$$

where C = soil cone index
b = tyre width
d = tyre diameter
δ = tyre deflection under load
h = tyre section height
W = load on tyre

The relationship between coefficient of traction (pull/load) and slip from the Single Wheel Tester data could always be represented by an expression of the form:

$$C_T = (C_T)_{max}\,(1 - \exp[-ks]) \quad \ldots\ldots (2)$$

where C_T = coefficient of traction
$(C_T)_{max}$ = maximum coefficient of traction
k = rate constant
s = slip

The relationships between $(C_T)_{max}$, k and M found from the data were:

$$(C_T)_{max} = 0.796 - \frac{0.92}{M} \quad \ldots\ldots (3)$$

$$k(C_T)_{max} = 4.838 + 0.061\,M \quad \ldots\ldots (4)$$

The above expressions are valid for stubble, ploughed and cultivated fields only, data from fields with loose surface trash or hard, dry grass fields gave results which were significantly different from all others. The tyres used in deriving these equations varied from 12.4 x 36 to 18.4 x 38 and a wide variety of loads and inflation pressures was used. The relationship between coefficient of rolling resistance (towing force/load) and mobility number was found to be:

$$\text{coefficient of rolling resistance} = C_{RR} = 0.049 + \frac{0.287}{M} \quad \ldots\ldots (5)$$

Using equations (2) — (5) the tractive efficiency may be found from the expression:

$$\text{tractive efficiency} = \eta = \frac{C_T(1-s)}{C_T + C_{RR}} \quad \ldots\ldots (6)$$

With the above restrictions in mind, and knowing the draught load on the tractor, equations (2) — (6) can be used to predict tractor field performance. As an example of the equations required to predict the draught load of various implements, the draught load of a mouldboard plough was modelled recently at NIAE using an analysis suggested by Krastin (1973). The plough was a 356 mm (14 in) semi-digger type and the predictive equation found to be:

$$\frac{D}{aw} = 13.3\,\nu\,a + 3.06\,\frac{\nu\,V^2}{g} \quad \ldots\ldots (7)$$

where D = plough draft force
a = depth of cut
w = width of cut
ν = soil specific weight
V = plough forward speed
g = gravitational constant

Using these equations the field performance of a 49 kW tractor was modelled when ploughing with the above mentioned plough. Measured and predicted values of work rate are shown in fig 1 and indicate quite good agreement (Gee-Clough *et al* 1977). Equations of the form of equation (7) for other implements will allow a full parameteric study of tractor-implement performance which can search for optimum combinations of power, weight, speed and draught load.

The value of fitting larger drive tyres, particularly in poor traction conditions may be demonstrated by tabulating predicted values of

Measured and predicted values of work rate

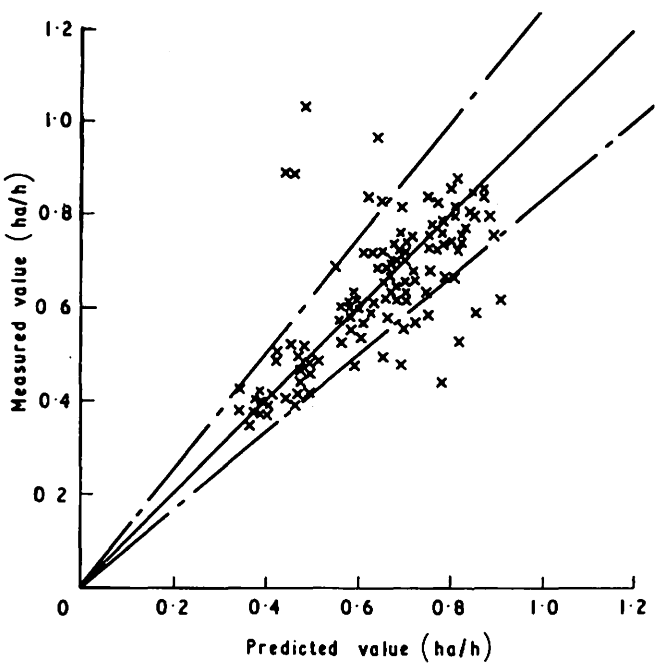

Fig 1 Comparison of measured and predicted values of tractor work rate when ploughing.
——line along which measured and predicted values are equal.
— · —lines outside of which predicted/measured value is greater than 1.2 or less than 0.8.

maximum coefficient of traction at different mobility numbers. This is shown in table 3. It can be seen from equation (1) that the mobility number is roughly proportional to tyre width and soil cone index value. Low values of cone index indicate poor traction conditions and obviously give low values of mobility number. Table 3 shows that if mobility number is increased from 2 to 4 the maximum coefficient of traction increases from 0.336 to 0.566, an increase of 68%. Doubling the mobility number can be accomplished by doubling the tyre width (eg by fitting dual tyres). A similar doubling of tyre width, changing mobility number from ten to twenty, changes the maximum coefficient of traction from 0.704 to 0.75, an increase of only 7%. Thus the main advantages from increasing drive tyre size will come when traction conditions are poor.

Table 3 Predicted values of maximum coefficient of traction at different mobility numbers

Tyre mobility number	*Predicted max coefficient of traction*
2	0.336
3	0.489
4	0.566
5	0.612
6	0.643
8	0.681
10	0.704
20	0.75

Traction aids

The field performance of conventional tractor drive tyres is relatively poor and this has led to the development over the years of traction aids which can be used in conjunction with the tyres. Typical devices include strakes, chains, girdles, half-tracks and cage wheels. The popularity of these devices has declined in recent years, partly due to the difficulties associated with fitting them in the field and partly due to the loads which they can impose on tractor transmissions.

There is little doubt however that some of these devices can produce an appreciable increase in tractive performance. Southwell (1964) tested several of these traction aids in five different field conditions and the test results are summarised in table 4. The cultivated sandy loam soil and heavy, wet clay were the two most

Table 4 Comparative performance of different traction aids (from Southwell [1964])

Configuration	Maximum sustained pull / *Static rear axle weight*		
	Cultivated sandy loam soil, dry and loose	*Heavy, wet clay soil. Surface wet and muddy*	*Average over all fields*
Air-filled 13.6 x 28 tyres	0.58	0.81	0.75
Air-filled 13.6 x 28 tyres plus wheel chains	0.54	0.80	0.76
Dual air-filled 13.6 x 28 tyres	0.56	1.09	0.89
Air-filled 13.6 x 28 tyres plus strakes	0.62	1.61	1.00
Air-filled 13.6 x 28 tyres plus half-tracks	0.80	1.15	1.06
Air-filled 14.9 x 28 tyres	0.59	0.99	0.85
Water-filled 13.6 x 28 tyres	0.54	0.92	0.76
Water-filled 13.6 x 28 tyres plus wheel chains	0.59	0.89	0.77
Dual water-filled 13.6 x 28 tyres	0.55	0.90	0.76
Water-filled 13.6 x 28 tyres plus strakes	0.67	1.31	0.96
Water-filled 13.6 x 28 tyres plus half-tracks	0.79	0.96	0.94

widely different soil conditions during these tests and the results in these fields have been tabulated along with the mean values over all fields. No matching of ballast was done between the air-filled and water-filled phases of the test and the effect of adding water would thus have been to add more ballast to the tyres. The two most effective traction aids in these tests were the half-tracks and strakes and this was so for both air and water-filled tyres. In the loose sandy loam soil which would have been a frictional soil with low cohesion the half-tracks were more effective than the strakes. However in the wet clay soil which would have been a high cohesion soil the strakes were more effective than the half-tracks. Both devices gave appreciable increases in maximum pull/static weight when compared to the tyre used alone.

Bailey (1956) compared the effects of strakes, girdles, ballast and a steel wheel and concluded that on sandy soils ballast was the most effective of these in increasing tractive performance. This may be compared to Southwell's results in the sandy loam soil which do not entirely support this conclusion. Bailey further concluded that on wet clay land the strakes were more effective than ballast, which is supported by Southwell's results.

What is indisputable from both these experiments is that traction aids can improve tractive performance considerably. For this reason a further study of some traction aids will be carried out at NIAE in the near future. The work will include the comparative performance of a commercial cage wheel and a flat-lugged cage wheel similar to those widely used in rice cultivation.

Soil compaction

It is tempting to state that if tractive performance is optimised then soil damage due to compaction will be minimised. There are occasions when this is true, for example lowering tyre inflation pressure or increasing the contact area of a tractive device will both improve tractive performance and cause less serious soil compaction. However, things are not quite so straightforward as this.

Raghavan *et al* (1977) found that soil compaction due to wheel slip was greatest in the region 15 to 25% slip. Since the maximum tractive efficiency of wheels in soil almost always occurs in the region 10 to 15% slip, the slip level which is aimed for to optimise tractive performance is not far removed from that which seems to cause maximum slip compaction.

Eriksson et al (1974) found that the degree of compaction caused by a given vehicle was mostly dependent on the soil moisture content at the time of passage, high soil moisture contents resulting in high compaction. The number of passes in the same wheel track also had a significant effect on compaction. Tractor size, tyre inflation pressure, fitting dual wheels and the effect of speed were found to be of less significance.

Soane (1972) measured soil compaction due to the passage of a

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two-wheel drive tractor, with and without cage wheels and a tracklayer of the same power. The tracklayer, even though much heavier than the wheeled tractor compacted the soil less. The commercial cage wheel was found to be ineffective in reducing compaction and it was stated that cage wheel diameter would have had to have been increased to take any appreciable load off the drive tyres.

Chancellor (1976) lists several ways of offsetting compaction effects. Amongst these are:

1 Limit the weight concentrated on any one area eg through multiple wheels (in tandem rather than dualled) or by fitting flexible tracklayer suspensions.
2 Reduce traction requirements so that the weight required per driving wheel can be reduced. This may be done by using all-wheel drive tractors, transmitting power to implements as in a rotary tiller or by increasing field speeds. Increasing field speed would allow tractors with a high power/weight ratio to be used.
3 Reduce contact pressures. Although reducing inflation pressure or increasing contact area do not always reduce the total volume of soil compaction, they do cause less reduction in soil porosity and cause the compaction zone to be near the field surface, where it can more easily be cured through tillage.

Although a great deal of work has been done on the effects of soil compaction, a great deal more remains to be done before quantification of the phenomenom can be attempted. What is required is a detailed mechanics which can readily and accurately predict the soil stress caused by, for example, the passage of a driven or towed wheel in soil. The stresses which must be predicted are not only those at the soil-wheel interface but those deeper in the soil itself. There are methods now available which give predictions of the stresses at the soil-wheel interface (eg Gee-Clough [1976]) and these methods are being refined to give more accurate predictions. Accurate predictions of the state of stress in the soil itself are much more difficult and at present require the use of digital computers (eg Yong and Fattah [1976]). This method is very cumbersome and cannot readily be used to analyse the vast number of combinations of tractive devices and soil conditions which need to be analysed. The quick and accurate prediction of soil stresses remains a formidable problem but one which must be solved before any great progress can be made.

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The management value of an increased number of available work days

J B Finney

Summary

IN practice the assessment of a work day is largely subjective and may vary between seasons. Machine capacity to give a reasonable insurance in any season is difficult to calculate. Tractor power available on farms is frequently five times greater than that theoretically required and yet in certain seasons this is insufficient.

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A BASIC requirement in farm management is to complete the necessary field operations by a specific date, with a limit placed on damage to the soil or the existing crop, and again with a limit placed on expenditure on machines and labour. Many of the management factors involved require subjective judgement. For example, what machinery capacity should be employed to give an adequate but not excessive insurance for all seasons? What soil moisture content, or interval of time since heavy rain, is required for acceptable field work? The answer to these questions will vary with the kind of operation and the pressure of events in any one season. The acceptance of the rate of working advantage of direct drilling over traditional methods may have to be balanced, in some cases, against expected yield reductions. The autumn cereal drilling season may be extended by starting earlier, but with the problem in some seasons of fungal attack and the expense of applying fungicides to control the attack.

The list of decisions that cannot be taken on a fully calculated basis is considerable. One of the leading workers in the field of machinery selection programmes says "The selection of an optimum farm machinery system is complex and cannot be described with simple mathematics" (Hunt 1969). This would appear, as far as British conditions are concerned, to be an understatement. The calculation of a machinery programme as a basis for a final decision can be helpful however, and it is certain that any increase in the number of work days available, through fortunate weather conditions or technical advance, is a major advantage to the farm manager.

Machinery complements

It should not be difficult for an individual farmer to calculate from his own records a reasonable machinery complement for an "average" season. Experience on the farm will indicate likely numbers of work days available and will include details peculiar to that farm — such as areas that are normally late at harvest, or poorly drained fields. Daily outputs from individual machines and men will be known. This information combined for a particular situation will be more accurate than generalised estimates for districts and groups of machines and will allow reasonably accurate estimation of machinery requirements.

What is extremely difficult to calculate, however, is the kind of machinery complement he would require for the difficult seasons and especially the very difficult season where timely autumn planting is not possible virtually regardless of the equipment available.

In these cases the options open to the farmer may be virtually impossible to cost. For example, if potatoes have to be lifted with several tractors in line in front of the harvester, the full cost of the operation in terms of soil damage is unlikely to be known. In many of these cases investment in more machinery may solve the technical problem of getting the work done, but would well set back the economics of the project. It has been suggested that the risk of untimeliness might eventually be covered by commercial insurance companies rather than the farmer's machinery system (Hunt 1969).

The margins of machine capacity commonly available are of interest. Consider a streamlined farming system on a clayland farm near Cambridge, on the basis of information provided (in Imperial Units) by the farmer (Sandercock 1977). The aim is to plant 172 ha (424 acres) of winter wheat and no other crops and the existing tractor complement, excluding tractors permanently fitted with fork-lift and sprayer, total a nominal 239 kW (320 hp). The aim is to finish planting by the end of October, so that in most years the situation is as follows:—

September 26 days work
October 22 days work
48 days at 7 hours useful work each day = 336 hours
Available at the drawbar — say 160 hp (at 50% nominal)
336 hours x 160 hp = 53 760 hp hr
Over 172 ha (424 acres) this represents 842 MJ/ha (127 hp hr/ac)

Accurate information is available on energy requirements for establishing a wheat crop on the land in question (Patterson D E 1969-77). The position is:—

Traditional (mouldboard plough) cultivation 280 MJ/ha (42 hp hr/ac)
Minimal (tined) cultivation 180 MJ/ha (27 hp hr/ac)
Direct drilling 60 MJ/ha (9 hp hr/ac)

There would appear to be safety factors of about 3, 5 and 14 times respectively, according to the system of cultivation adopted.

This situation commonly exists on arable farms today. The calculated power requirement, based on the best information available for a "normal" season, doubled to give an insurance margin, would by experienced managers generally be considered to be totally inadequate.

It might be interesting to consider how these comparatively large margins are translated into planting dates on this farm. The cultivation system in use is of the order of the "minimal" system (180 MJ/ha, 27 hp hr/ac) and in most years the crop can be sown by the end of October. In difficult years, even with the apparent margin available, some of the land will not be planted in the autumn and will have to go into the less profitable spring cropping. Difficult years include those that are too dry after harvest for work to continue so that, incidentally, some doubt is cast on work day calculations based on soil bearing strength and dates of return to a given moisture content. For example, in 1976 combining ended on 29 July and drilling started on 14 October (an extremely dry year). In 1974 — a wet year — combining ended on 14 September and drilling started on virtually the same date as in the dry year of 1976 (13 October). It should be noted that on this farm the aim is to start sowing in the last week of September and any departure from that date suggests problems in getting land ready and suitable for drilling.

Table 1

	1968	*1973*	*1974*	*1975*	*1976*
Days from end of combining to 15 October	1	44	31	49	78
Days *after* 15 October when drilling was completed	57	14	26	10	48

Grange Farm, Knapwell, near Cambridge

The effect of wet (1968) and dry (1976) seasons. 15 October is taken to be optimum drilling date.

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The 5 x factor mentioned for this farm applies to "average" date of end of combining and reasonable autumn conditions. Consider a season that was dry and soil strengths were such that 230 MJ/ha were required for crop establishment, rather than the normal 180 MJ/ha and where the onset of heavy rain shortened the season by 15 days. The arithmetic becomes:—

33 days x 7 hr x 120 kW x 3.6* = 99 792 MJ

Over 172 ha, this is 580 MJ/ha

Thus in an unfavourable situation the power available is still 2½ times that apparently required and the "performance gap" needs some explanation. Part of the answer is already available in the output recorded where tractors are operating for maximum performance, when outputs are in line with the calculated figure, compared with farm figures where output is commonly a half or less than a half of that possible (table 2) (ADAS 1972).

Table 2 Long Sutton 1975 — Tractor Ploughing demonstration

	4WD	*2WD*	*Crawler*
Nominal power kW	71	70	67
Drawbar kW (assumed 50%)	36	35	34
Ploughed area ha/hr	1.01	0.73	0.85
"Apparent" MJ/ha at the drawbar	128	173	144

The performance of the best tractors in this demonstration indicated that 50% of nominal power could be available at the plough. The poorest performance gave an equivalent 292 MJ/ha.

An important aspect of days available for field work is that there should be some measure of the quality of those days. Even if daylight hours are no longer important, there are likely to be differences in tractor and implement performance that should be considered. There is little information available, but an example from a single winter season at Boxworth Experimental Husbandry Farm is of interest.

The site chosen was wheat stubble on well drained, highly permeable boulder clay and the autumn of 1971/72 was neither exceptionally wet nor dry. The performance of the same 2- and 4-wheel drive tractors, together with a plough and cultivator, were examined at intervals through the period mid-September 1971 to mid-January 1972. Soil moisture contents and drain performance were monitored, together with other soil physical characteristics. The general outline of the results is illustrated in fig 1 and 2. The first point of interest was that the performance of both 2- and 4-wheel drive tractors declined sharply with the first showers of rain near the end of September. Once this lower level of performance had been established, the situation did not change very much throughout the period. Poorer performance was recorded where the tests were carried out during or immediately after heavy rain, (plots, dates and times were fixed at the time of planning the project), but the situation recovered during the drier spells. Four wheel drive performance, on a total tractor weight basis, changed with that of the 2-wheel drive tractor and at no time up to 17 January, the last time the comparison was made, was there any suggestion that 4-wheel drive was "running away" from the 2-wheel drive tractor.

Throughout this period the soil moisture content (0—150 mm samples bulked) increased gradually. The draught of the plough and cultivator, using the same implements each time and operating them in a randomised plot arrangement, increased generally as a result of increased adhesion of soil to the shares and mouldboards.

It would appear from this single example that provided this land is draining freely, which in effect means that previous cropping and field traffic has not done serious damage, there will be long periods during the autumn when daily work output will not markedly change. This work only referred to naturally freely draining soil, traffic on undisturbed stubble and implements that work well at high moisture levels. Information on other situations would be valuable (Davies 1973).

The performance of tractor tyre equipment under moist soil conditions has been investigated by ADAS (Davies 1973) from the point of view of soil damage rather than efficiency of output. Correct choice and use of tyres might give a 10% improvement in output, which is valuable, but small compared with other possible improvements in the use of time available. Where improvement in tyre use might be of great value is in avoiding or reducing soil damage, thereby improving traction conditions for succeeding operations.

Work was carried out at or near the lower plastic limit on both heavy silt and boulder clay land. Various combinations of tractor weight and wheel slip were compared and soil damage was measured in terms of shear strength, penetrometer resistance, soil density and tyre sinkage. The indications from this work on both soil types were that excessive slip caused more damage than high wheel loading in every case, but that for a given slip higher wheel loads caused greater damage.

The conclusion is that tractor power should be utilised through higher forward speeds and lower draught (normally narrower) implements, coupled with adequate ballasting. There are obviously practical limits as to how far this principle can be taken. The financial advantage to the farmer of avoiding some soil damage could not be assessed in these experiments, but it can reasonably be assumed that any improvement on the more sensitive soils is desirable. Further, it is useful that the techniques which give greatest mechanical efficiency also result in the least soil damage.

The possibility of changing techniques to make maximum use of available work days

Available work days between the harvest of one crop and the planting of another have been shown to be only part of the story (table 1). The "work day" has to be compatible with the job under consideration and there are management possibilities for rearranging some operations. Among these examples might be:—

Mouldboard ploughing suits the sequence of spring sowing operations better than the autumn situation. The mouldboard plough works best with a considerable amount of moisture in the soil — the level considered ideal by many ploughmen is near field capacity. Corn drills work best when the soil is comparatively dry. This suggests that ploughing through to drilling is best suited to a progression from wet to drier conditions as during the spring, whereas autumn conditions normally progress from dry to wet. In a dry season ploughing might be held up and even if ploughing is possible, it can be difficult to break the clods produced. Further, in this situation the cultivation aimed at breaking the clods is likely to cause the loss of any moisture that may be present to set off germination. At the other end of the moisture scale, if land is being disturbed by ploughing and traditional cultivation, and is then exposed to prolonged rain, it is particularly susceptible to surface saturation and loss of bearing strength. The traditional answer in this situation is to plough and either drill immediately on to the furrow or use a combined cultivator and drill (possibily the NIAE bridge link system). The more modern answer to both the extremely dry and extremely wet situation would be direct drilling, with its apparent greater tolerance of early planting (ADAS Eastern Region 1977) and much earlier emergence under dry conditions. With the options of three disc, single disc and tine coulters available, direct drilling can be carried out in the extremes of moisture conditions. At the dry end of the scale, moisture conservation is maximum and emergence normally much quicker than under traditional systems, and under wet conditions the undisturbed soil gives the greatest possible bearing strength for field traffic. Therefore while direct drilling shows a considerable advantage in work rate and reduced power requirement in any season, it would appear that the extremes of seasons are when the technique is of maximum advantage. The exception to this rule is where autumn moisture levels are so high that harvest traffic causes major rutting of the fields which cannot be tolerated for true direct drilling. The only answer to this problem is the return to the minimum amount of cultivation necessary to restore a reasonably level field surface.

Furrow press equipment for light land has produced in effect an increase in available work days. The traditional system has been to plough very light land and re-consolidate it by various cultivation treatments before drilling. Spring drilling was thus delayed until the land could be consolidated. Where land is furrow pressed at the time of ploughing — and with an automatic hitch on the press this is an easily combined operation — drilling in the spring can be carried out without any additional work. The result can be drilling achieved very early in the year (late January/early February) which is generally necessary for maximum yields on the lightest soils (Gleadthorpe Experimental Husbandry Farm 1977).

Autumn application of potash and phosphate fertilisers again makes use of the greater bearing strength of undisturbed soil for field traffic and the less urgent work periods of late autumn. Further, these fertilisers do not need to be supplied annually (for

→*page 106*

** 1 kW hr = 3.6 MJ*

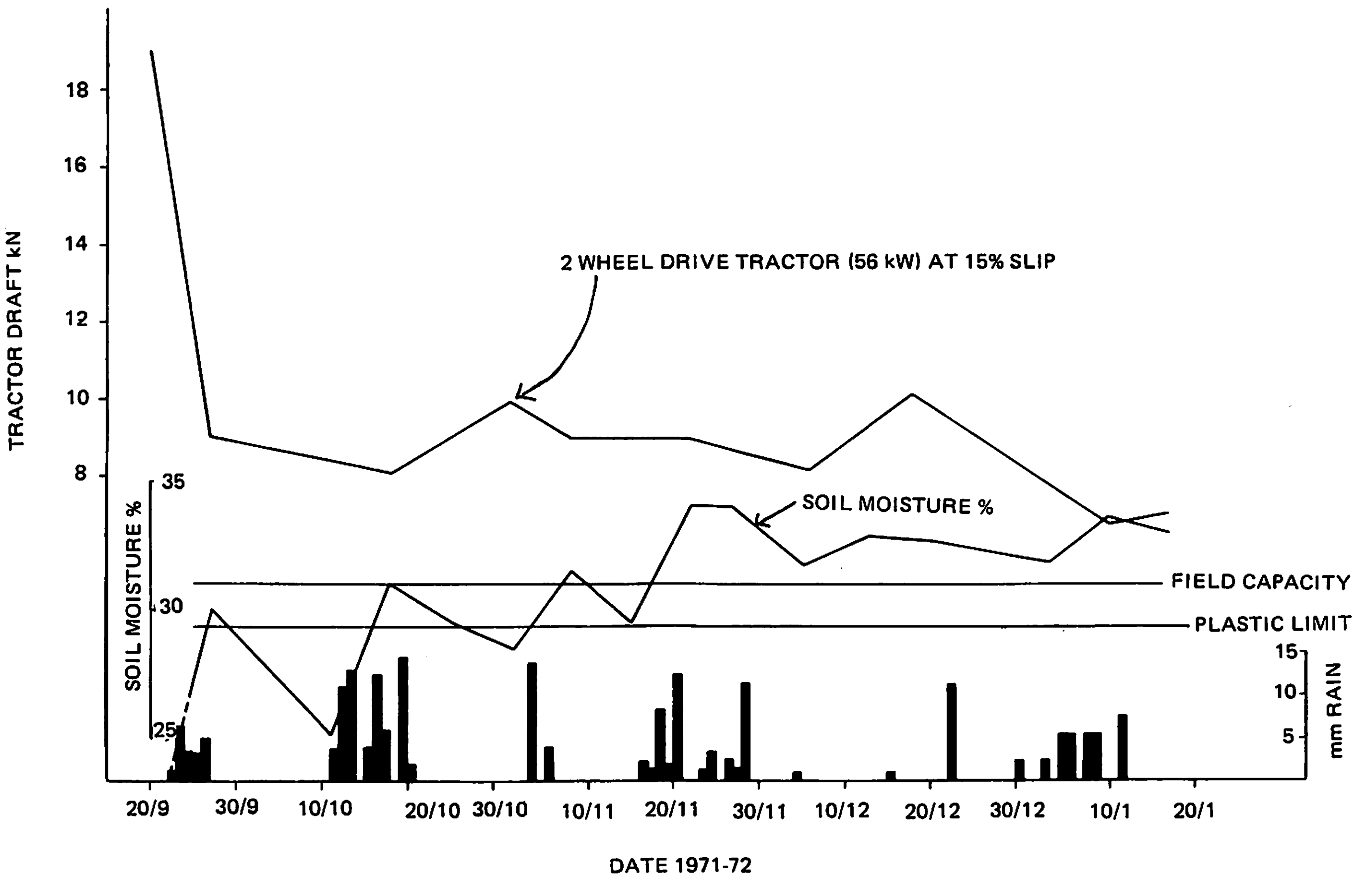
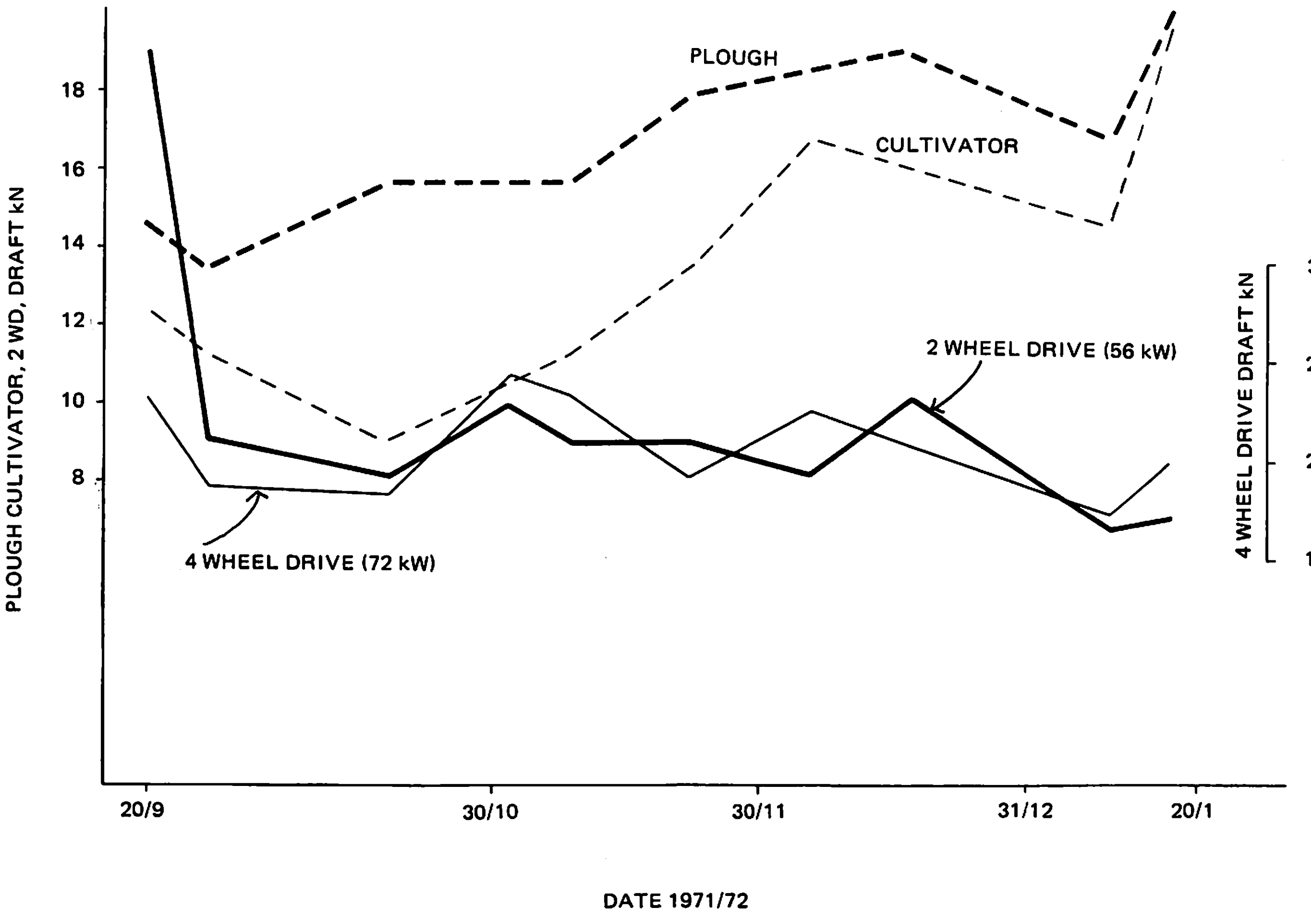


Fig 1 (above) Fig 2 (below)



some purposes three year intervals may be satisfactory) and if one-third of the farm is being treated each year, there would be scope for missing a year if circumstances were difficult. The result is the freedom to use vehicles that would not normally be suited for cultivated land in the spring, the option to use cheaper "straight" fertilisers in bulk and quicker and earlier working during critical spring work periods.

Among many other techniques that have been suggested and tried for extending work days are means of reducing drift in spraying (hot air treatment of the spray, electrostatic charging of the spray, large droplet production and simple shielding of the spray unit), ultra-low ground pressure vehicles for winter work under saturated conditions and ultra-low volume spraying to cut down loads. In many of these cases the aim has not merely been to extend the season. It has been the only hope of carrying out the necessary operation at the correct time.

Conclusion

Most farms have equipment that gives a large margin of capacity in the average season. The example quoted refers only to tractors and cultivation, but there is evidence of large margins available in other aspects of field work such as root harvesting and combining (ADAS 1970–1974). There is also evidence that the capacity available could be better used.

The use of the work days normally available, and their extension, could possibly be made more effective by changing techniques rather than by adding to the total machinery capacity available. For example, doubling the machinery and labour bill for cultivations would not be acceptable, whereas halving the effort put into cultivation is often technically easy and not detrimental to yield.

A gain in available work days may give a rapid return in increased revenue. It may mean that autumn cropping can replace spring cropping, or that spring crops are planted on time. In other cases more available work days will lead to a higher degree of precision in each operation and to an improvement in profitability that may be long term and more difficult to assess.

Finally, it must be stated that the problems of the farmers who struggle with root harvesting in difficult seasons, when there are never enough tractors and no amount of calculation will help, are fully understood.

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Work days for field operations

Edited summary of discussion

Paper 1

Dr B D Witney (Edinburgh School of Agriculture) opened the questions by asking if the undersown cereals included in the rotation to allow more timely ploughing, were utilised by livestock.

Mr Birkett replied that no stock were carried on the farm, but leys included in the rotation achieve three things. Ploughing is made easier, soil workability in the Spring is improved, and they help to maintain organic matter.

Mr R H Blakeman (ADAS) asked what criteria Mr Birkett used in deciding between use of cage wheels or dual tyres.

Mr Birkett considered that under drier conditions, better flotation was achieved with pneumatic tyres, whereas cage wheels were used when the soil was wetter, as during the late autumn.

Paper 2

Mr D R F Tapp (County Tractors) enquired if there was any alternative to using the calendar as a guide for field operations, for example by using long-range weather forecasts.

Mr Jarvis replied that any method must be related to soil moisture content. Better systems for predicting work days could no doubt be developed.

Mr C V Smith (Meteorological Office) commenting on Mr Jarvis's point that calendar date is not entirely satisfactory in selecting optimum sowing date, observed that it should be possible to utilise physical, weather dependent factors, such as soil temperature, rainfall, and soil moisture status which can be measured.

Paper 3

Dr B D Witney (Edinburgh School of Agriculture) asked about the preparation of spring seed beds. Is it better to cultivate early with large tractors and then purchase flotation tyre equipment to work on a dry crust which has been produced by evaporative drying, or is it better to go on to the field later in the spring and work the undisturbed soil with large tractors and cultivation equipment?

Mr G Spoor (NCAE) said that if soil disturbance was necessary, it was much better to cultivate early in autumn to make maximum use of winter weathering to produce a tilth, rather than wait until spring before cultivating. Although undisturbed soil in spring is very trafficable on the surface and therefore capable of being direct drilled, the moisture content below the top 50 mm is frequently too high to allow satisfactory soil tilths to be produced.

Mr R G Sturdy (Soil Survey) asked if the NCAE observations on soil drying had covered a range of soil types.

Dr Godwin reported that the experiments were mostly conducted on heavy clays of the Wicken Series.

Paper 4

The Chairman, Mr Maddison, observed that various measurements of soil factors can be made, but what is needed is a simple measure to provide a single index of workability.

Mr Thomasson considered that this depends upon the degree of classification required. Shear strength is a good guide for instant classification, but as a general index to a soil's character, no one single measurement was suitable.

Mr Spoor added that from scientific measurements there is no suitable all-embracing property and at present it is difficult to better the subjective measurement of "the experienced farmers' boot".

Paper 5

Mr B H Parker (Land Drainage Service, ADAS), referring to the data presented asked if 'frost days' should be taken into account in assessing workability?

Mr Armstrong replied that frost days had occurred, but had been excluded from the data, to ensure that only direct water table effects were considered.

Mr D G Christian (Letcombe Laboratory, ARC) queried the basis on which Mr Armstrong ascribed 'workability' and 'trafficability' as being the same thing.

Mr Armstrong agreed that there was a difference, but on the crude scale used, it is difficult to distinguish between these two concepts, as the data could not withstand such detailed analysis.

Mr A J Thomasson commented on Mr Armstrong's statement that Autumn 1976 was a typical in that soils wetted from the top downwards in that year. He said that in his experience rain on dry soil always moistens the upper layer first and this is the important layer from a workability point of view.

Mr J E Gregory (Land Drainage Service, ADAS) asked if the scale for determining workability was too subjective and did this lead to a variation between regions in the determination and assessment of soil conditions.

Mr Armstrong replied that this was a possibility as steps had not been taken nationally to reduce regional bias.

Paper 6

Mr H J Westlake (ADAS Farm Management Group) commented that workday recording and prediction must be based on potential rather than actual workdays, and must be related to individual farm jobs.

Mr Smith agreed saying that the analysis that was carried out in the East Midlands had been extended to include potential workdays based on rainfall data rather than actual workday data which might possibly include stoppages not directly associated with rainfall. Regarding the question of individual farm jobs, Mr Smith said that it is necessary to look at each operation separately and to develop the appropriate criteria.

Dr Witney described his work with Mr Oskoni at Edinburgh where they are developing a cumulative soil moisture content model as part of a project on determining tractor power requirements for tillage operations. This model takes account of daily precipitation, evapotranspiration, run-off, and drainage, whereas existing methods generally ignore drainage, or acknowledge only a fixed rate by using a drainage coefficient. This assumes that soil will drain at the same rate throughout the year, and is obviously not suitable for a cumulative assessment.

Relating drainage to hydraulic conductivity of unsaturated homogenous soils, at a depth of 30 cm, has produced good agreement with field conditions when near field capacity. Work is continuing to confirm the theory for drier soils, before developing a selection procedure for work day probabilities based on both soil moisture content, and limiting weather conditions, as identified by Mr Smith.

Mr Smith reported that he had to convert original data (recorded before the development of the neutron probe) based on input of rainfall, and output via evapotranspiration, to a form appropriate for estimating soil moisture deficit. He found that it was necessary to introduce a 'percolation factor', as evaporation alone did not account for total losses in soil moisture.

Paper 7

Mr S E Niemeyer (Seal-Hayne College) asked if the use of traction aids was likely to increase damage to soil structure.

Mr Gee-Clough said that considerable damage can result from the slipping and sinkage of pneumatic tyres and that in his opinion the bite holes caused by strakes and half-tracks were not so bad.

Dr Witney enquired if it was thought better to remove ballast from single rear wheels rather than increase contact area by adding a second set of wheels.

Mr Gee-Clough considered that either reducing the load, or increasing the contact area, decreases soil damage, and it is better if one can do both.

Mr D R F Tapp referred to the NIAE tyre tests which record maximum slip, and asked if they were considering the effect on overall performance at lower slip values (eg 5%).

Mr Gee-Clough reported that modelling work was being undertaken to enable prediction of this.

Paper 8

Mr D R F Tapp (County Tractors) referring to the farm case-study observed that the farmer was later than his target date of 15 October each year, yet Mr Finney asserted that the farm had enough power in hand. What should the farmer therefore do to finish sowing his winter wheat by this date?

Mr Finney thought that the answer was not to take on more labour or machinery, but to introduce newer techniques of cultivation. He should retain his present power units, and therefore still have a power "insurance factor" if he ran into difficulty. However, the problem is really a question of frequency with which the 'exceptional' years (eg 1968 and 1976), occur.

Mr T C D Manby (President) asked if Mr Finney would enlarge on other restraints on the workday situation, and whether farm transport is a restriction on the harvesting of farm crops.

Mr Finney stated that the list of restrictions is considerable, and cited examples of straw baling rather than burning, and the transport requirements of a multi-stage beet harvesting system as typical restraints on field workdays.

General discussion

Mr R D Bowers (Booker Agriculture International Ltd) gave an example of how workday data had been used as a planning aid in the setting up of a sugar cane factory in the West Indies. The data have been used to assess factory daily inputs and assess machinery requirements, as well as helping to solve transport problems.

Mr Birkett said that he had kept records of rainfall and the time taken to complete each operation on each crop since 1963; these data were taken into account when changing machinery.

The Chairman, in reply to the previous question agreed that a suitable formula for prediction of workdays is required. However, the problem is that in certain tropical areas, weather conditions are more uniform than those experienced in UK.

Mr Bowers accepted that there were large variations in UK, particularly in the rate of evaporation when compared with tropical situations, and so an additional time factor must therefore be introduced into calculations.

Mr Gee-Clough added that the NIAE work used a model based on the cone index. If the variation in cone index was provided, they could predict whether any particular vehicle would be able to work satisfactorily on the land.

Mr G A Longbottom (Farmer, Essex) referring to Mr Gee-Clough's observations on tyre treads said that these did not tie in with his own observations. He had observed 2 identical tractors subsoiling with similar machines with different tyre treads, and one was getting along much faster than the other! With regard to half-tracks Mr Longbottom said that he had made use of these when spraying and drilling but he could not now get them to fit some tractors with the new quiet cabs. In reply, Mr Gee-Clough said that he could only restate his results from the NIAE, namely that only small deviations in performance had been found from tyre treads on commonly used tyres. He also agreed that half-tracks could be useful in the circumstances quoted by Mr Longbottom.

Mr Manby and **Dr Godwin** emphasised that slight differences in working depth and in tractor linkage geometry could in themselves change a situation from a "go" to "no go" condition.

Mr Birkett said that whilst he was in theory in favour of tracked vehicles, on his farm they did not match the performance or flexibility of tractors with pneumatic tyres.

Mr R F A Murfitt (NCAE) asked if there was any potential in the use of air-cushioned vehicles in agricultural situations. Many operations such as spraying or transport are not soil engaging, and such a vehicle could be season-independent in terms of workability of the soil.

Mr Gee-Clough referred to the work by Prof Wong at Carlton University, Canada, evaluating such vehicles. There is a considerable problem in that aerodynamic steering devices do not operate satisfactorily below speeds of 50 knots. NIAE have had a little experience with an air cushioned trailer, and found that spray and sideways stability were the main problems. Any practical device would therefore have to employ steering wheels in contact with the soil. The economics of such a device are questionnable.

Mr Tapp asked Mr Finney about the relative performance of the 2-wheel drive and 4-wheel drive tractors quoted in his paper. Mr Finney replied that on a weight for weight basis a 4-wheel drive tractor is significantly better, although in the example quoted in his paper, the comparative performance of the two tractors under the changing soil conditions throughout the autumn in question, were similar.

Referring to Mr Finney's point that the way to make the best use of the workdays available was to change cultivation techniques, Mr Manby said that this had been the aim of the Cultivations Department at the NIAE when they designed the rotary digger. It is able to cope with extreme soil conditions as well as the more normal situations. A slow speed rotary digger takes account of all available tractor power, does the minimum required in moving the soil and lets the weather do the work at the surface.

Referring to Mr Gee-Clough's work at the NIAE, Mr Finney asked if soil damage decreases above the 25% slip. Mr Gee-Clough said that soil damage assessed in terms of increase in soil density reached a peak at 25% slip and then decreased above this figure.

Summing-up

Mr Maddison in summing up the days proceedings quoted the remit of the meeting, which was "To discuss techniques for predicting and increasing the number of field work days on the farm to improve crop yield and reduce soil damage."

"A number of factors have been discussed including soil types, weather data, tyres, design of tractors, but it seems that we have a long way to go before we can achieve prediction of work days with any degree of accuracy. It is good that all sides to this question have been represented here today, and substantial progress has been made by our meeting."

Rice parboiling

D J Greig

OF the estimated annual world production of more than 300m tonnes of paddy less than 5% enters world trade as an export crop compared with 25% for wheat.

Most non-exported paddy is produced and consumed in the countries of Asia where it forms the basic foodstuff supplying the energy and nutritional requirements of millions of people. Because of its great importance as a major foodstuff it is not unreasonable to expect that it should meet their nutritional requirements. Raw milled white rice unfortunately does not; parboiled white rice is much more likely to supply essential vitamins.

The starchy endosperm of the paddy kernel makes up only about 70% of the grain weight, and, after milling and polishing, forms the familiar white rice. The outer abrasive and indigestible husk accounts for about 20% of the grain weight and currently is mainly used as fuel. The remaining 10% of the kernel is made up of a number of layers of different cells lying between the husk and the endosperm. These layers, together with the germ, contain most of the kernel's valuable vitamins, proteins, mineral salts and oils.

Rice milling usually is taken to include the twin processes of removing the outer husk to produce brown rice (husking), and then removing the highly nutritive layers surrounding the white endosperm (polishing) to produce white rice. Rice is unique amongst the cereal grains in that it is normally cooked and consumed in the form of whole grains. Broken grain is not valued as highly as whole grain by most consumers so that the value of a paddy crop is very much influenced by the yield of unbroken rice after milling and polishing. The proportion of broken grain generally lies between 3% and 10% by weight when using modern rubber roll hullers and cone polishers on raw paddy.

The machinery used for husking and polishing is only partially responsible for these high rates of kernel breakage. During the later stages of ripening, minute cracks develop in the endosperm which give rise to planes of weakness and subsequent failure during milling. This causes a serious loss in revenue in commercial milling operations.

Brown rice, ie paddy with only the husk removed but with the bran layers still adhering to the endosperm, has considerably more nutritive value than that of polished white rice produced from raw paddy. Parboiling is a process which reduces grain breakage during processing and redistributes nutrients within the kernel.

Parboiling

Water, heat and time are the important factors in parboiling. The process consists of rewetting paddy to at least 30% moisture content (wet basis) and then heating it in order partially or wholly to gelatinise the starch. The parboiled paddy is then re-dried to a safe moisture level for storage or for further processing. During the heating process the minute cracks in the endosperm are filled and strengthened so reducing breakage during subsequent milling operations. Under carefully controlled conditions, using graded paddy, broken grains can be eliminated giving a whole grain yield of about 72% of the paddy — an important consideration in commercial milling operations.

For the majority of consumers, however, the real value lies in the redistribution of the vitamins, oil and mineral salts from the intermediate layers into all parts of the grain, giving a more nutritious white rice. Also, because those enzymes present in raw paddy which cause rancidity are destroyed, the parboiled paddy and also the white rice produced from it can be stored for much longer periods without deterioration. It is primarily for this reason that parboiling has become established practice in some countries of Asia.

Parboiled paddy also has an increased resistance to insect attack and is much easier to mill and polish. The white rice produced has a translucent appearance and tends to remain firm after cooking so that grains remain discrete and do not become sticky — a valuable feature for boil-in-the-bag rice. In addition to its enhanced nutritive value it is also more easily digested. In spite of its advantages, parboiling is not universally practised. It is not found in Japan, where farmers market brown rice, and in Thailand it is carried out only on paddy for export.

Grains damaged during growth or harvest tend to discolour during the parboiling process, the degree of darkening depending on the colour of the husk. Where the endosperm is exposed, either by insect or fungal attack or through mechanical damage, the grains may become extremely dark coloured either completely or only in the damaged areas. These discoloured grains may be removed, after husking and polishing, by electro-optical sorting machines, as described on pp 109–111.

Parboiling methods

A clean and uniform paddy sample is a prerequisite for a successful commercial parboiling operation, the steeping and heating time depending primarily on the grain thickness and the degree of parboiling required. Where the heat and moisture treatment is allowed to reach the centre of each kernel a completely translucent grain is produced. With less harsh treatment a white opaque centre to each kernel is retained.

Traditionally, the process consists of steeping the paddy for up to four days in cold water, followed by steaming at atmospheric pressure for up to four hours and then sun-drying. This prolonged steeping allows fermentation and the development of both off-flavours and discoloured grains to an extent often unacceptable to local residents and consumers. However, the method is still widely practised.

The Indian Paddy Processing Research Centre at Tamil Nadu has developed a technique in which sodium chromate is added to the steeping water to eliminate fermentation and reduce smell. The endosperm does not appear to absorb the chromate. After sun-drying on uncovered concrete surfaces the paddy is milled and the husk used for raising steam.

In some modern commercial plants such as in the Italian Crystal Process the cycle time for parboiling has been reduced to a few hours by using hot water at about 70°C for steeping, first under vacuum, then under pressure, followed by steaming in pressure vessels at pressures up to one atmosphere.

These autoclaves have a steam heated jacket and steam pipes inside the vessel and are rotated about a horizontal axis during steaming. Condensate is removed during this process to ensure an even moisture penetration into the kernels. Drying is carried out in the same autoclaves under a partial vacuum, the energy for drying being provided by the internal steam pipes and external jacket. The batch of parboiled paddy is removed from the autoclave at between 18% and 20% moisture content and is then forced-air cooled in louvred bins where it loses up to 2% more moisture.

The parboiled paddy is stored in a tempering bin for some hours before being milled at about 16% moisture content. The yield of unbroken head rice is up to 72%, and special drying equipment has been developed to dry the white rice after processing.

A variation of the crystal process is used in Burma. After steeping, the paddy is put into baskets which are placed in an autoclave for steaming. Initial drying is carried out in a continuous flow column drier, air being heated by a husk burning furnace supplemented by an oil burning unit for adequate control of drying air temperature.

Major disadvantages of the modern parboiling plant are its high initial cost and the skill required for its successful operation. High utilisation is essential. Even with round-the-clock operation, parboiling is likely to increase the cost of white rice by up to 10%. But a more nutritious product results and at the same time the yield of head rice per hectare is increased. Parboiling is an energy consuming operation, but recent improvements in furnace design, when combined with a milling plant producing husk, have enabled all the heat energy required to be obtained from less than half the husk produced. The development of a husk fired producer gas plant feeding a low speed gas engine and generating electricity, and utilising the remaining husk, would make the whole process self-sufficient in energy and would free the operator of a major husk disposal problem.

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Rice — Post harvest grading by means of electrical-optical sorters

H Stirling

Summary

THE background to electro-optical sorting of rice is discussed and the requirements for 'Peck' and 'Chalky' defect removal are identified, both in the context of consumer preference and phytosanitary standards. The operation of a typical electronic sorting machine is explained, and its performance is described. Consumer grading specifications are outlined, and the author concludes with a discussion of the present and future roles of sorters in the rice industry.

Introduction

Rice (*Oryza Sativa*) is one of the most important food grain crops, and provides 60% of the world staple diet. Some 350 million tonnes are produced/annum, at an average yield of 2.4 tonnes/hectare, and practically all of this is consumed in the countries of origin. Only about 9 million tonnes (2.5%) finds its way into the export market, of which about 1 million tonnes goes to the developed world, and 5.5 million tonnes to the developing.[1] One fifth of the total world production is processed by parboiling which can take place in either the producing or the importing country. In recent years, the popularity of parboiled rice in the developed world has steadily increased.

The presence in edible rice, either white or parboiled, of partially or totally discoloured grains lowers its quality, and consequently its saleability. This is generally because of consumer preferences, and not for nutritional or phytosanitary reasons. Nevertheless, discolouration is very often the result of post harvest insect infestations and mould infections. Typical stored products pests are the rice weevil (*Sitophilus oryzae*) and the grain moth (*Sitotroga cerealella*). Strains of mycoflora found in rice include *aflatoxin*, which is carcinogenic, and *penicillium citrinum*[2] which is associated with calcification of the urinary system, although both these moulds are frequently the result of incorrect parboiling treatment, in particular, inadequate drying; they are not found on rice which is parboiled in the developed world.

Other impurities commonly experienced are mud balls and small stones, seeds, rodent droppings and miscellaneous foreign matter; these, together with discoloured grains, can be classified as 'peck'. An additional defect, not a discolouration, is the 'chalky' rice grain; this has a chalky white appearance, and the grain completely disintegrates on cooking resulting in a mushy porridge. As a general rule 'peck' is associated with parboiled rice, 'chalky' with white milled rice.

Because of the similarities in shape, size and weight between good grains and defects, it is not possible to separate them accurately by mechanical means, and an optical inspection and separating system is really required. The simplest way of doing this is to feed the commodity in a single layer on a flat belt, with operators visually inspecting it and removing, by hand, any defects. The process can be speeded up by the use of flexible suction pipes which the operator places over the defective grain. Even so, the average extraction speed an operator can reach is only about one grain per second[3], and hence the cost of sorting depends on the percentage contamination in the input.

However, during the last twenty years, the growth of electronics has made possible the automation of the eye and brain functions, and fully automatic electro-optical sorters are commercially available for the removal of 'peck' and 'chalky' defects from rice.

There are a number of advantages in automating this process:

1. Electronic sorters can operate at much higher throughputs than manual ones.
2. The efficiency of sort is improved because the grains may be inspected in two directions, as opposed to one with the belt technique, and because the inspection system is not subject to operator fatigue.
3. The sorter can operate at the same throughput irrespective of the input contamination level.
4. The process is more acceptable in the developed world with high labour overheads.

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How an electro-optical sorter works

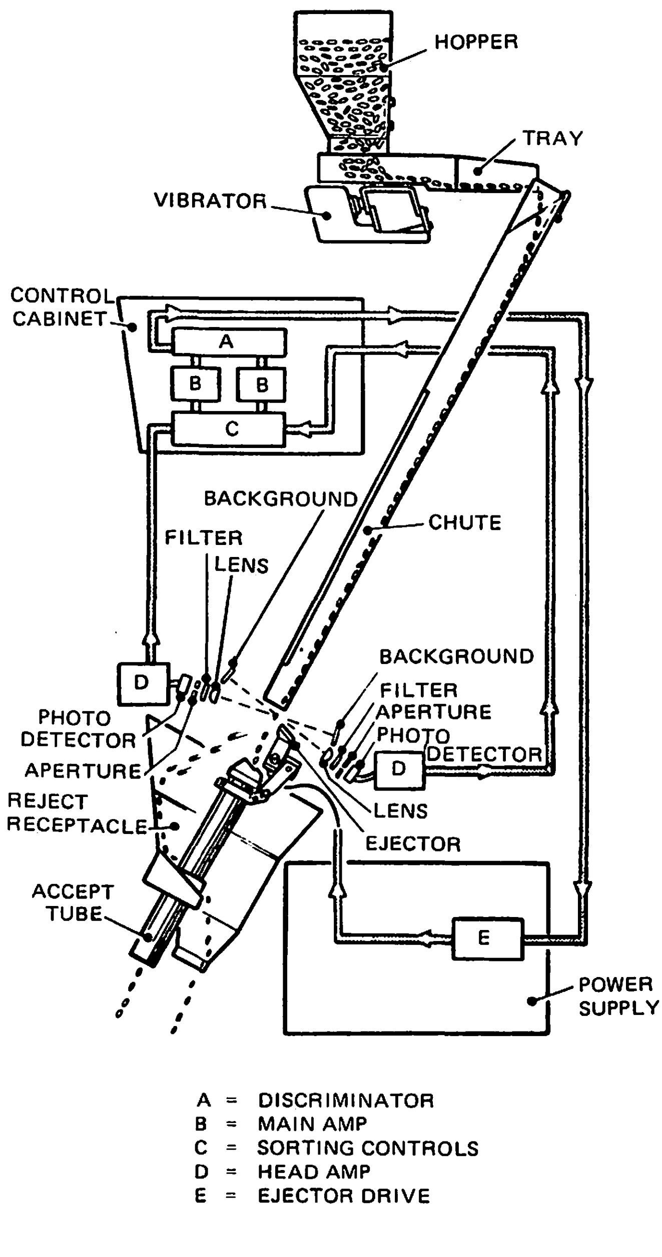
An electronic sorter consists of four basic parts, shown in fig 1.

(i) *A Feeding system* to provide a controlled feed to the inspection area.
(ii) *An inspection system* to measure the optical properties of the particles.
(iii) *An evaluation system* to translate the optical measurement electronically into an accept/reject signal.
(iv) *A separation system* to remove reject particles by means of a precisely timed air blast.

Feed

The feed system meters the appropriate number of particles per unit time by means of a vibrating tray. From this, the particles drop on to an inclined chute down which they accelerate under gravity to speeds as high as 4 m/sec. The chute also aligns the product stream into the optical centre of the inspection area..

Fig 1 Schematic diagram of electronic separator.



A = DISCRIMINATOR
B = MAIN AMP
C = SORTING CONTROLS
D = HEAD AMP
E = EJECTOR DRIVE

Inspection (see fig 2)

The inspection technique is based on the measurement of reflected light and, to a lesser extent, transmitted light. The "sort" depends on the fact that differently coloured particles have, at certain wavelengths, different reflectivity and absorption values. The optical box is evenly illuminated by fluorescent tubes on two sides. Photocell detectors view the particle stream from the two other sides of the box, filters being incorporated in the viewing aperture to select the optimum waveband over which the measurement should be made. The particles are viewed by the detector as they fall in front of an illuminated background. The colour of this is chosen so that it appears to have brightness between that of the accept and reject particles. In practice, this means that a dark particle will give a decrease in signal whereas a light particle will give an increase, and an unambiguous decision can easily be made by the electronics.

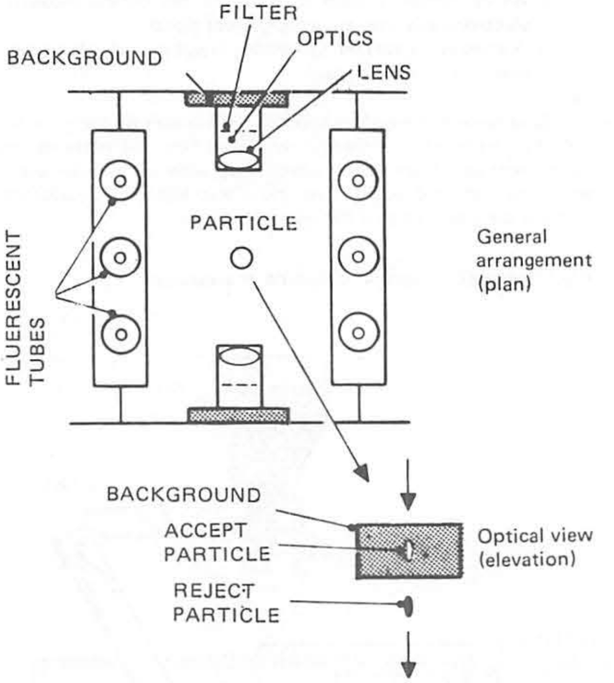


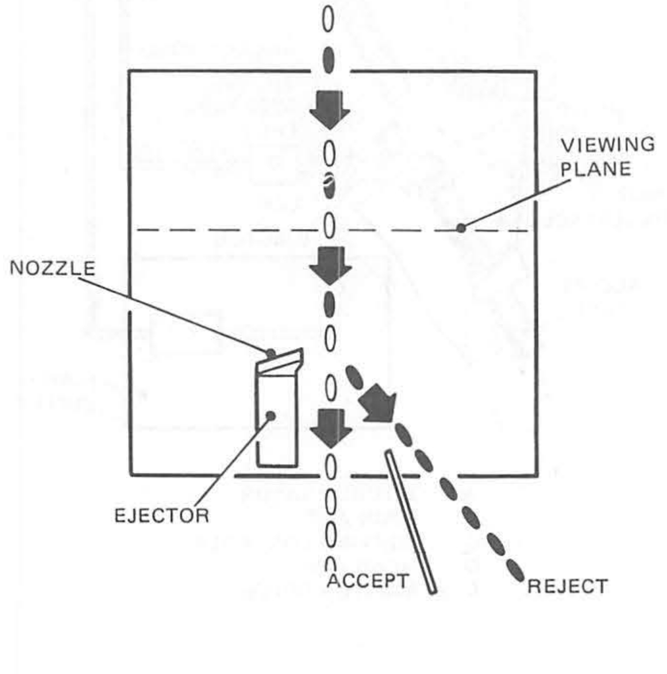
Fig 2 Optical box (plan)

Evaluation system

The signal from the solid state detectors has first to be amplified. This is done by a low noise, low level current amplifier, placed close to the detector to avoid interference problems. The amplified signal can then be passed on to the decision-making circuits. These take the form of a level discriminator which classifies all signals of a certain polarity and exceeding a certain noise threshold as reject signals, and the corresponding particles as reject particles.

The final link in the chain is the ejector drive circuit which couples the decision output signal to the separation system.

Fig 3 Optical box separation system (side elevation)



Separation system (see fig 3)

The separation system or ejector consists of a high speed solenoid valve which releases short blasts of compressed air through a nozzle. This ejection device exhibits the essential features of rapid action, reliability and mechanical strength. The separation process takes place whilst the particles are in free fall. Accepted particles are allowed to continue along their normal trajectory into an "accept" receptacle whilst the carefully controlled air blast deflects the rejected particles out of this trajectory and into a "reject" receptacle.

The whole process is extremely fast, the ejector being capable of removing 600 reject grains every second.

Sorting performance

The actual performance of rice sorters under plant conditions may now be examined. A typical machine is shown in fig 4, and its performance on 'peck' removal from parboiled rice is described in fig 5; this assumes that the commodity has passed through the normal mechanical cleaning and screening stages prior to colour sorting.

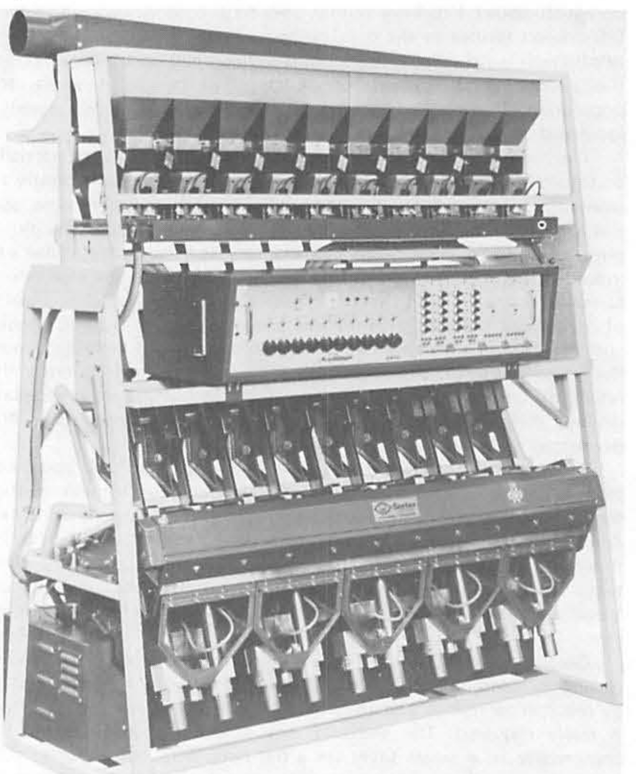
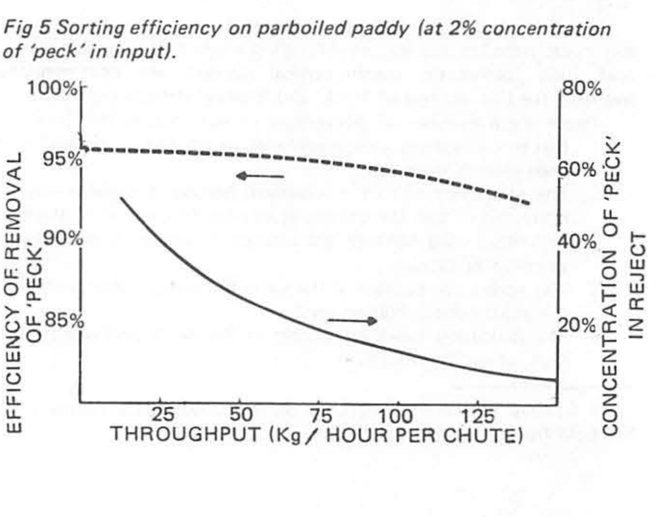


Fig 4 A ten channel colour sorter

Fig 5 Sorting efficiency on parboiled paddy (at 2% concentration of 'peck' in input).



Peck in the input of 2% (after mechanical screening) and throughputs of 60 kg/hour per channel are considered typical; (ie total throughputs of 0.35 and 0.6 tonnes/hour per six and ten channel machine respectively). At these levels, it can be seen that 95% removal of the 'peck' can be achieved, and that the resulting concentration of 'peck' in the reject commodity will be of the order of 22%. As the throughput increases, both the efficiency of removal and the 'peck' concentration in the reject decrease. The actual nature of the defect will influence these curves; for example, a tip defect in which only the end of the grain is discoloured is harder to detect than a totally discoloured grain. Consequently, a sample containing a preponderance of totally discoloured grains will be sorted more effectively than the efficiency curve describes. Tip defects normally account for 30% of the total 'peck' in parboiled rice.

The value of parboiled rice is sufficiently high to warrant, in many cases, a re-sort of the reject product which may contain 80% good grains. Consequently the input conditions change dramatically, with an increase in 'peck' concentration from 2 to 20%; surprisingly this does not significantly depress the overall sorting efficiency.

With white milled rice, the total discoloured defect level is often only 0.2%, with no tip defect grains; this is because many of the defects in raw paddy are shattered at the milling and polishing stages, and subsequently removed by screens and pre-cleaners. However, the level of 'chalky' grain contamination in white rice can be anything from 5–30%, with removal efficiencies around the 90% mark. This separation cannot normally be undertaken without making minor modifications to the optical box lighting in the sorter.

Specifications

Different countries obviously have different grading standards; the following is from Japan, and serves as a general guide:

Grade 1 – very white but no rejects in 1 200 pieces.
Grade 2 – white but no rejects in 1 200 pieces.
Grade 3 – very white but 1 reject in 1 200 pieces.
Grade 4 – white but 1 reject in 1 200 pieces.
Grade 5 – white but 3 rejects in 1 200 pieces.
any more than this and the rice is unacceptable.

An electronic sorter is capable of upgrading rice with 2% 'peck' contamination to meet a specification of 1 reject in 1 200 pieces. At contaminations of 1.5% or less grades 1 or 2 are theoretically attainable, but in practice, due to the 'very white' requirement, grade 1 is rarely achieved.

There is no international legislation on mycotoxin levels, although a number of countries issue *aflatoxin* guidelines and EEC legislation is on the way. In the UK the level is up to 50 parts per billion, but both the USA and Denmark are on zero-tolerance. As yet, no manufacturer of electronic sorting machinery makes any claims for efficiency of removal of mouldy rice grains, despite the fact that the rejection of discoloured pieces will be, indirectly, beneficial.

However, with increasing international pressure to formulate such legislation, together with the tremendous advances being made in the electro/optical field, it is not unreasonable to presume that, during the next decade, the new generation of sorting machines available will be capable of effectively meeting this requirement.

Discussion

Rice is a vital food commodity for much of the world's population. A large proportion of it is consumed in the countries in which it is grown, many of which are in the developing world. However, rice consumption is increasing in Western countries, some of whom are now highly efficient producers, others who are millers and processors of imported paddy.

The consumer orientated markets of both the West and the East have well defined grading standards to which the commodity must conform to be saleable, or to achieve the optimum price, and, generally speaking, it is not possible to upgrade rice outside these specifications by conventional mechanical screening techniques.

Electro-optical sorting is a well established grading system in the food industry, and, when applied to rice, is an effective method of removing 'peck', 'chalky grains', and other defects from contaminated product, and converting it into a saleable commodity with associated economic advantages.

At present, this is only carried out for consumer preference reasons, but it is possible that within the next few years, the state of the art will have advanced sufficiently to be able to use electronic sorters for upgrading mould infected product to meet impending international phytosanitary legislation.

Acknowledgements

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References

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2 **Parpia H A B.** *Mycotoxins and mycoticoses*. Mysore, Central Food Technological Research Institute (Unpublished report).
3 **Gariboldi F.** *Rice parboiling*. FAO Agricultural Development Paper, No 97, Rome (1974).

LYTRMAG is a new electro-magnetic base drill stand produced by the Lancashire engineering company, Archbell Greenwood Limited. They have produced this type of machine for several years both for their own use and for other local companies.

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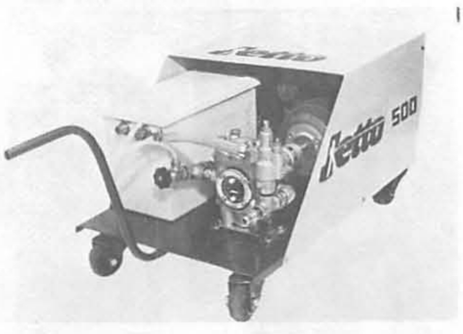

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