THE AGRICULTURAL ENGINEER

JOURNAL and Proceedings of the INSTITUTION of AGRICULTURAL ENGINEERS

Volume 37 Spring 1982 No 1 (ISSN 0308-5732)

The mechanical farm of 2030

See page 303

Institution of Agricultural Engineers

Spring National Conference
(in association with West Midlands Branch)
on Tuesday, 16 March 1982
at The National Agricultural Centre, Stoneleigh.

Engineering for Meat Production

The objectives are to:
(a) review the full range of factors influencing the development of meat production technique
(b) review the more recent and significant engineering developments in this field
(c) identify the potential contribution of Agricultural Engineers to future developments.

Conference Chairman: Dr K Baker, Director of Operations, Meat and Livestock Commission.

Speakers:

Professor P Wilson, Chief Agriculturalist, British Oil and Cake Mills/Silcock Ltd, will discuss factors influencing meat production in the future.

P Spencer, Bernard Matthews Ltd, will discuss housing and feeding systems for poultry.

A Smith, Agricultural Development and Advisory Service, National Pig Environment Specialist, will discuss the housing and feeding of pigs.

Dr M Kay, Head of Animal Husbandry Division, School of Agriculture, Aberdeen, will discuss meat production from ruminants — future demands on the Engineer.

S W R Cox, Deputy Director, National Institute of Agricultural Engineering, will discuss monitoring animal performance.

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ISSN 0308–5732

Volume 37 **SPRING 1982** **No 1**

The AGRICULTURAL ENGINEER is published quarterly
by the Institution of Agricultural Engineers
West End Road, Silsoe, Bedford MK45 4DU

Tel: Silsoe 61096

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Price £3.50 per copy, annual subscription £14.00 (post free in UK)

Contents

Three categories of paper appear in the Journal:—

a) Papers submitted to the Honorary Editor and subsequently refereed.
b) Conference papers not generally refereed but which may be if the authors so request and if the refereeing process can be completed before the Conference Report is due to be published.
c) Mechanisation and review articles not normally appropriate for refereeing.

Front cover: The mechanical farm of 2030 will likely be run by one man from a computerised office

Soil management for cereal production~Introduction

J S Rymer

IN writing an introduction to the papers which formed the substance of the Autumn National Conference at St Ives entitled "Soil Management for Cereal Production", I can do no better than to quote Sir Nigel Strutt in his foreword to the "Soil Report", published by the Agricultural Advisory Council in October 1970.

"We have encountered many problems of great variation in different parts of the country; these are influenced by soil, climate, habits and attitudes and many other factors, not least being the availability of money. We have chosen, however, to regard the national farm as a series of fields being patients having a medical check-up, and by these standards we cannot find it in a perfect state of health. The Council have been deeply concerned about the flattening graph of increasing yields which has shown itself in recent years on some of our most productive land".

Cledwin Hughes was then Minister of Agriculture and was being badgered by NFU members to redress the balance between horn and corn because the so called barley boom was then in evidence and many farmers felt this was leading to irreparable damage to the nation's legacy — its soil.

I was privileged to take part in the work of the Report and travelled with other Council members to many countries where soil problems had been reported. The publication of the Report was significant, to the extent that for the first time since Arthur Young had been required to report to the Board of Agriculture in the second half of the 19th century, the Minister of Agriculture had asked for an independant report on the health of the nation's soil, at a time of great change in British agriculture. The Report successfully rekindled an interest in what happens under the surface of fields and probably stimulated the considerable effort which has applied in the last decade in various Research Institutes on work, which continues with creditable vigour in a number of important areas.

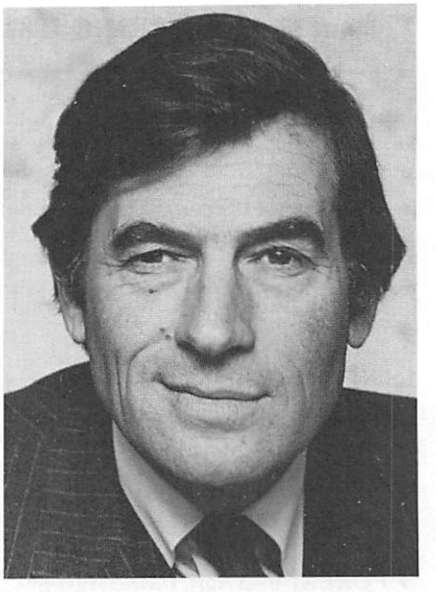
The measurement of "improvement" by the application of different "Soil Management" regimes is a difficult task. Whilst final yield is the normal criterion examined, Farmers and research workers have become increasingly aware of the need for long term studies which record reliability and repeatibility of results and take account, not only of direct energy requirement, but of indirect energy requirement in the form of fertiliser and agrochemical usage and cost.

Agricultural historians may well regard the seventies as the decade of soil structure awareness, in that farmers and advisers have given the problems of compaction and seed bed conditions more thought than ever before. The eighties therefore provide the engineer with better documented problems to solve and a challenge worthy of both time and effort.

I was honoured to be asked to take the Chair for this one day Conference organised jointly by the Institution of Agricultural Engineers and the Agricultural Development and Advisory Service. The President of the Institution of Agricultural Engineers, Mr R F Norman, introduced the morning session by drawing attention to the need for engineers to be made aware of the exact nature of the problem. Mr K A McLean, ADAS Mechanisation Adviser at Cambridge was Conference Convenor and had assembled six expert speakers plus a successful farmer, the latter to review the relevance of the papers to his own farming situation.

The attendance of over 400 interested delegates, drawn widely from many contrasting interests involved in the business of producing food successfully from soil, confirmed the wisdom of the organisers in their choice of subject. The lively discussion during the intervals and over the well chosen lunch boxes provided further evidence that the content of the papers was sufficiently provocative to stimulate some creative controversy.

Ken Hubbard, the ADAS Agronomist based at Cambridge, opened the proceedings with a review of cereal requirements and responses and then Gordon Spoor from the National College of Agricultural Engineering gave an excellent paper on the Cause and Nature of Soil Damage. David Patterson, Head of the Cultivations Department of the National Institute of Agricultural Engineering, reviewed systems and was followed after lunch by Dr Traulsen from the Department of Agricultural



Engineering and Farm Buildings of the Schleswig-Holstein Chamber of Agriculture, who gave an extremely well presented paper on the advantage of ploughing.

Brian Finney, newly appointed as Senior Mechanisation Advisory Officer of ADAS, gave a timely review of discs and their value as a primary cultivation tool. Bryan Davies, the Chief Soil Scientist for ADAS at Cambridge, who has been closely involved with the MAFF Joint Consultative Organisation work on cultivation, then reviewed current soil problems and the experimental programme which may eventually provide answers to some of the most hotly debated issues.

Finally, Richard Dawson, a highly articulate farmer from Essex, gave a spirited review of the day's contributions and concluded with his solution to cereal farming without straw burning.

All concerned with the day seemed pleased with the response and it was clear that at least the farmers attending would go away resolving that next year they would get it right — no smearing or compaction, timely deep loosening but only where it was needed and with everything sown into perfect seed beds.

The papers that are reprinted in full are well worth reading and studying — they contain a lot of distilled wisdom from a body of dedicated men.

J S Rymer is Managing Director of J S R Farms, Driffield.

Agronomic requirements of cereal crops and their effect on soil management strategy

K R Hubbard

AUTUMN sown cereals now constitute some 80% of cereal production Eastern England, spring barley seeming to be relegated to something of a residual crop often only grown because of the constraints of previous cropping. Thus in this paper I intend to deal with the agronomic requirements of autumn cereals, largely winter wheat and winter barley, since this is the area which poses the greatest problems in terms of soil management to ensure the best soil enviroment to realise the yield potential of our current varieties of winter cereals.

Need for high yields

THE advent of completely new horizons in crop protection for winter cereals over the past decade together with the development of new varieties capable of considerably greater response to applied nitrogen fertiliser, coupled with a few years of particularly favourable weather conditions for cereal production, has led to the adoption of high input systems from which high yields have to be achieved to make the enterprise economically viable. Inflation has resulted in fixed costs on mainly cereal farms in the eastern region reaching about £350/ha and with the variable costs of some high input systems being of the order of £240/ha, a yield of 6 tonnes/ha is necessary to break even. Even with more moderate levels of variable costs, which are unlikely to be much less than £150/ha at least 5 tonnes/ha is needed (about the national average yield of wheat) in order to break even. Thus for the factors which are within our control, we must be certain of being able to ensure the best possible conditions for the crop to achieve yields well in excess of the break even points in order to make reasonable profits.

Fortunately both of winter wheat and winter barley are extraordinarily flexible and are able to compensate in various directions to make up for deficiencies. This is true even at comparatively high levels of yield, but clearly, to achieve consistently high yields over large areas year after year, certain standards of crop establishment and structure must be achieved. However the advent of new varieties with large ear size potential has considerably increased this flexibility. Yield is purely a product of grain numbers per unit area and grain size. High grain number can be achieved in a variety of ways which can interact with grain size but the latter is in part a genetic factor which can be considerably influenced by green leaf area duration. Thus a wide range of crop structures can achieve a similar end, but as a reasonable insurance for high yields, good soil conditions and structure for establishment is essential.

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Water availability

Availability of water to the cereal plant is a critical factor with regard to the ultimate yield of that crop. Not only does water need to be available but the plant must have sufficient root structure and volume in order to make full use of the available water. During the period of rapid increase in crop dry matter from April to July, vast quantities of water are used. For each tonne of above ground dry matter produced the crop uses approximately 250 tonnes of water. A good crop producing, say, 7 tonnes/ha of grain with a harvest index of say 45, needs an above ground dry matter total of about 15 tonnes. Thus a water supply of some 375 mm is required during these 3½ months. Average rainfall in Eastern England is unlikely to supply much more than 175 mm of this, so to achieve yields of this magnitude the soil must be able to supply, and the plant must have the root structure to extract, approximately 200 mm. Clearly many soils are unable to do this and it is only in years of high rainfall in June and early July that the light to medium soils can support these yields. With other aspects of husbandry at a sufficiently high level the heavier soils can only achieve this if they have adequate structure to a depth of at least 1 m to allow roots to make full use of the available water in the profile. Thus drainage and subsoil management on these soils is fundamental to high yields.

At the beginning of plant development water is obviously important for germination and plant establishment and soil management of seedbeds plays an important part. When drilling is carried out at the normal time in the autumn, seedbed moisture is not usually a problem but is of increasing importance if sowing is advanced into the middle or first half of September.

The yield and price structure of winter wheat compared with barley has caused many farmers to maximise the area of this autumn sown crop. In addition winter barley, particularly the feed varieties, is now generally preferred to spring barley because of normally higher yield and in spite of higher input costs, generally greater profitability. Other plus factors are rotational considerations eg entry for oilseed rape, earlier harvest and an improved cash flow. Hence on many farms all of the cereals are now autumn sown and this poses problems in terms of seedbed preparation. In spite of increased power and cultivating capacity, many have resorted to minimum cultivations and direct drilling coupled with considerably earlier sowing in order to achieve target areas.

With regard to the effect of time of sowing on yield, both winter barley and winter wheat are extraordinarily flexible. For the medium to heavy soils it would seem that the optimum timings would be between 20 September and 20 October, but the penalties for being outside this range are unlikely to be very great. On the lighter soils experimental evidence from winter barley trials suggests that sowing in the earlier half of this period is likely to have an advantage over sowing in the latter half. I think this is likely to be concerned with water availability in the spring and early summer which enables the earlier sown crops to normally get through their development stages before severe water stress occurs.

Weed, pest and disease problems

New methods of autum soil management for cereals which may not involve the use of the plough, are leading to increased problems in weed, pest and disease control. Earlier sowing means that there is less opportunity for germination and subsequent destruction of seedlings of annual grasses such as blackgrass and brome. The lack of inversion of the soil also increases the carry-over of grass weeds, particularly those with seeds of low dormancy. The adoption of these management techniques would be impossible without adequate herbicides but fortunately our armoury of chemicals and our knowledge of how best to use them is still developing rapidly. Many of these, however, do depend on soil activity so cultivation practices need to be designed to ensure optimum herbicide activity.

Earlier sowing is also encouraging new pest problems such as Opomyza and the aphid vectors of barley yellow dwarf virus. Similarly disease problems such as mildew and rhynchosporium on winter barleys on lighter land are becoming more frequent. Both these and the weed problems mentioned earlier will necessitate a full facility for being able to apply crop protection chemicals right throughout the winter period. Whilst development of suitable low ground pressure vehicles for this purpose is part of the answer, soil management and cultivation strategy must increasingly be planned with this requirement in view.

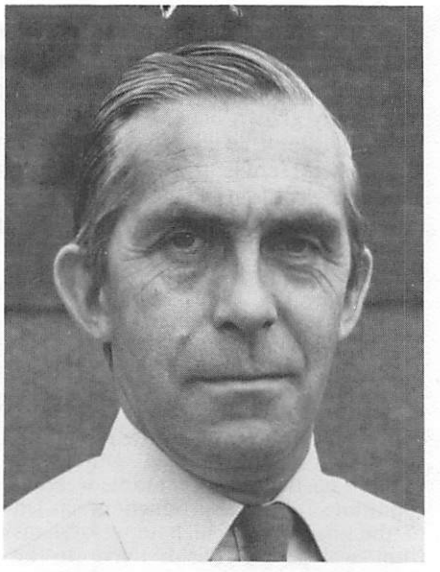
The causes and nature of soil damage

G Spoor

Abstract

THE causes and the nature of soil damage in the form of inadequate soil tilth, compacted and smeared layers and soil structure degradation are discussed. The extent of likely soil damage from different mechanisation operations under different soil conditions is considered together with the tillage and management implications of overcoming and avoiding such damage.

Soil physical damage can be defined as any soil change which is detrimental to the development and production of the crop. Damage is a relative term and can only be considered in the context of the optimum soil conditions required for crop production. Soil damage can arise from both natural causes and management practices and decisions on tillage requirements should be related to existing damage problems. This paper considers the causes and nature of the problems which may occur and discusses the management implications for minimising and alleviating damage. These considerations should assist in the planning of field operations and in the selection of equipment to minimise the damage risk and overcome the problems through tillage.



Soil physical conditions required and the nature of problems

CONSIDERATION must be given to both the crop and the mechanical operation requirements in the production of a cereal crop. Depending on the growth stage, different soil requirements are needed for germination, emergence, early seedling development and subsequent root growth. Mechanical operations such as soil preparation, drilling, fertilising, spraying and harvesting, have to be carried out on the soil. The soil conditions required to meet these separate and sometimes conflicting requirements can be summarised as follows:—

a) adequate tilth and trash control for germination, emergence and effective action of herbicides
b) absence of capped, compacted or smeared layers which could impede water infiltration and the downward movement of roots and water
c) adequate soil strength to support surface traffic.

The ideal soil condition would therefore be one where an adequate tilth existed with a strong soil matrix to provide support, but filled with continuous pores to allow effective root and water movement. Any departure from this will create problems.

Four types of soil damage problems frequently occur:—

a) inadequate tilth, either too fine or too coarse
b) destruction of soil structure
c) smeared and locally compacted layers with the loss of the large soil pores
d) general compaction.

Whilst poor germination may occur with excessively coarse tilths, very fine tilths can create even greater problems, particularly with autumn sown crops. Fine tilths are very prone to capping, have low infiltration rates and are slow to release water to the lower soil layers, thus the risks of surface waterlogging are high. Work by Cannell *et al* (1980) with winter cereals, has shows these crops to be most susceptible to waterlogging at the pre-emergence stage. At this stage, waterlogging delays emergence and reduces populations. In their experiments on winter wheat, 16 days waterlogging killed all seedlings and 6 days waterlogging depressed plant populations to 12% (clay soil) and 38% (sandy loam) of the control. Compensatory growth reduced the effect of this on yield, which was finally depressed to 82% of the control on clay and 84% of control on sandy loam. The increasing need for finer seedbeds for the effective action of pre-emergence herbicides and rapid germination of early drilled autumn cereals, will increase the risks of surface waterlogging in wet autumns.

Adequate soil structure is required on all soils except the coarser sands to provide a sufficient number of large pores for adequate root, air and water movement. Any destruction of structure will reduce the number of these pores.

Smeared and compact layers just below seed depth restrict early root development, cause waterlogging and encourage the production of toxins which will kill the seedlings if straw is present in the waterlogged zone of the top soil (Ellis, 1977). Impeding layers at greater depths can reduce the availability of water later in the growing season by restricting root zone depth and can also cause waterlogging in the root zone later in the growing season.

Causes of soil physical problems

These undesirable soil changes can arise as a result of natural processes or mechanical ones where the soil is loaded by tractors and machinery.

Natural changes

Unwanted changes due to natural processes can take the form of soil structural collapse, surface capping due to both raindrop action and structural collapse, and the blockage of larger pores due to soil leaching and infill. Soils of weak structure are more susceptible to these processes, but all soils are at risk if drainage is poor and waterlogging prolonged. Figure 1 shows the natural settlement which occurred during relatively wet and dry winters, on a weak structure silty soil of the Agney Series and s strongly structured clayey soil of the Hanslope Series described by Spoor *et al* (1977). The greater the degree of settlement and compaction on the weakly structured soils and in the wet winter can readily be seen. Bad drainage would have aggravated this problem further.

Not all natural changes are deleterious however, some can help overcome damage, providing the soil drainage status is good. Weathering action can improve structure and assist in tilth production in the surface layers. The swelling and shrinkage action in soils containing swelling clay minerals aids root penetration during water deficit periods and in some circumstances, may reduce compaction problems. Certain soils, including calcareous clays are effectively self cultivating soils; such action minimises, if not eliminates the need for tillage.

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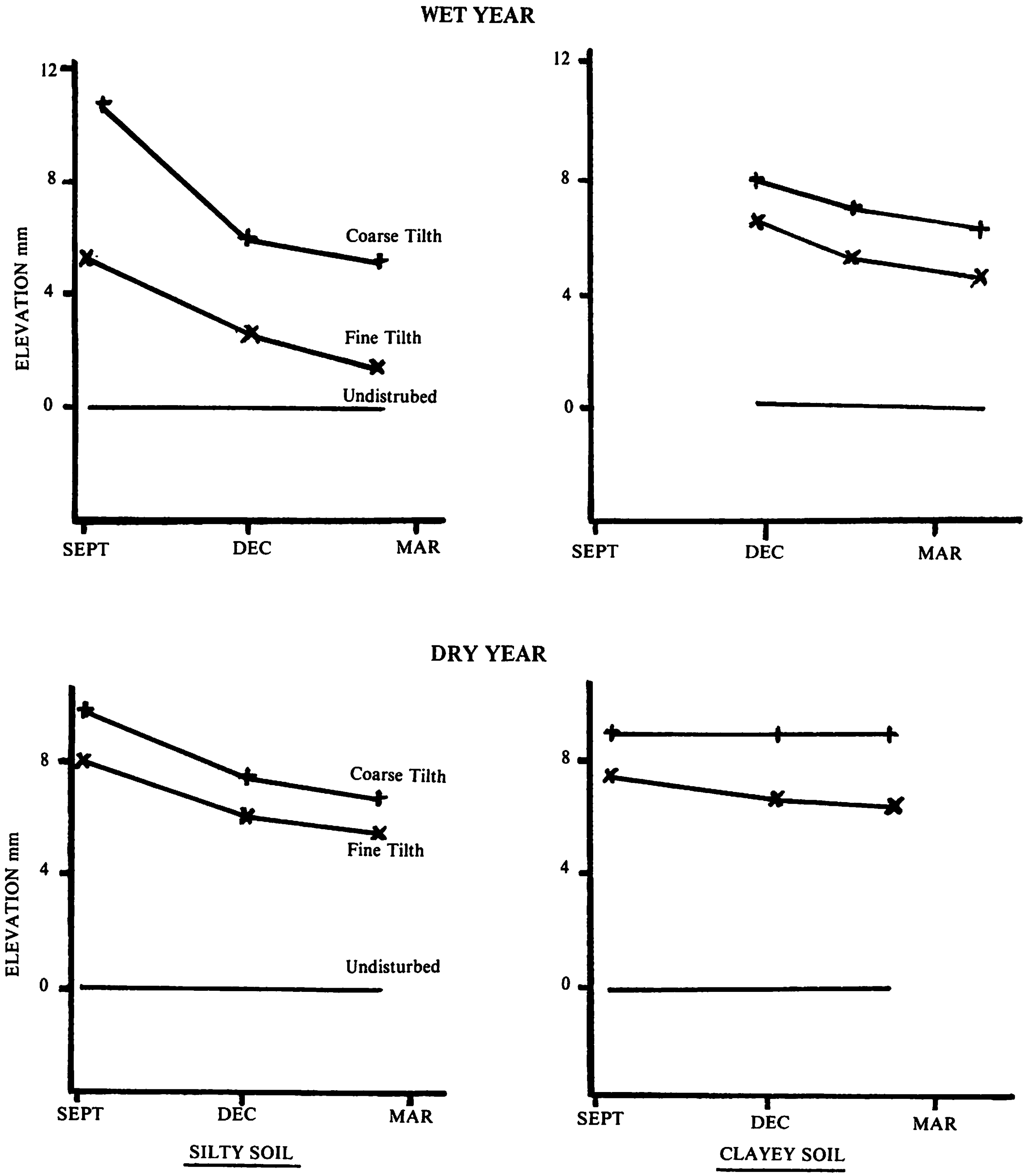
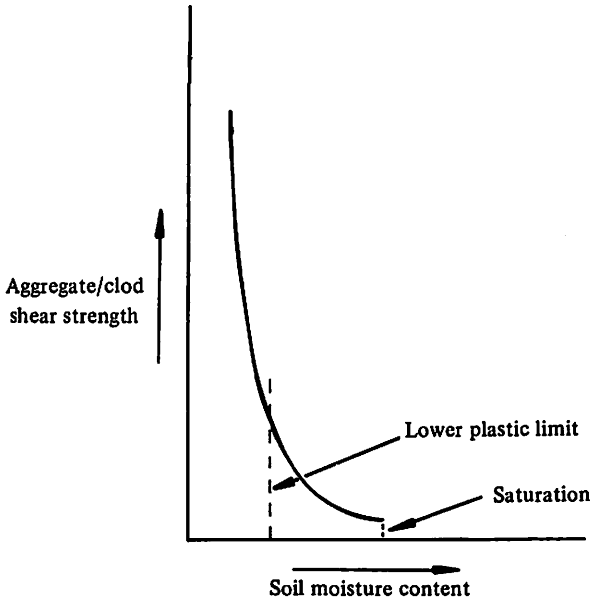


Fig. 1 Changes in surface elevation of two soils with time in wet and dry years



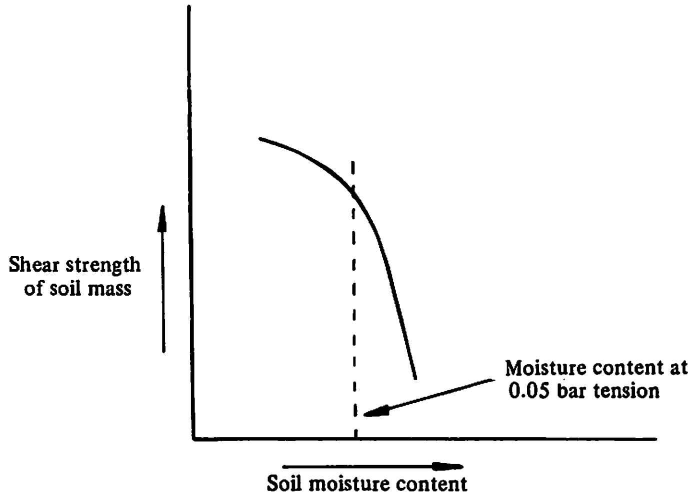


Fig 3 Relationship between strength of soil mass and moisture content

Fig 2 (left) Relationship between aggregate strength and soil moisture content

Mechanical changes

Three types of soil damage can occur as a result of mechanical loading; structural breakdown, compaction and smear. A local horizontal compacted layer and smear are the forerunners of soil pan formation. Whether damage actually occurs or not on loading, depends on how the soil deforms. Soils can deform in two ways:—

a) along a few well defined slip planes, with a decrease in soil density, termed 'brittle failure'
b) along many failure planes, the soil density increasing, termed 'compressive failure'.

Soils are most likely to sustain damage when they deform compressively.

Before any volume of soil within a soil mass can move, it usually has to displace or slide over the soil surrounding it and the resistance of movement depends on the soil shear strength. Compressive failure and hence potential damage is most likely to occur when the resistance of this surround is high. This is likely to occur in practice when significant downward loads are applied to the soil. Upward forces tend to produce brittle, loosening failure at shallower depths, but as the resistance to upward movement increases with increasing working depth, brittle failure can change to compressive failure. The transition depth has been defined as the critical depth by Spoor and Godwin (1978).

Implements such as cultivation tines, subsoiler tines and plough shares, which are inclined forwards to their direction of travel, apply upward forces to the soil and so cause brittle failure unless working below their critical depth. Backward inclined tools such as rolls, the edge and convex side of discs, wheels and tracks apply downward loads giving compressive failure with resulting soil compaction. Wear on cultivator tine and plough share often creates a backward inclined lower edge, which will tend to produce compaction immediately beneath the edge, even though the soil above is being loosened.

The degree of compaction which occurs during compressive failure depends upon the relative magnitude of the soil shear strength and the mechanical load applied. The lower the soil shear strength the more susceptible a soil will be to compaction. Shear strength is very dependent on soil moisture content, and dry bulk density, the denser soils tending to be the strongest. Figures 2 and 3 illustrate the change in strength of the clods and structural aggregates and of the complete soil mass with changing moisture content. Figure 2 shows that clods and structural aggregates are very weak at high moisture contents and hence very susceptible to breakdown if worked in this state. The strength of the soil mass is also low at high moisture contents, Figure 3, but increases very rapidly as the soil dries from saturation to moisture tensions or water table depths of approximately 0.5 m. The benefits attainable through reduced compaction, from waiting until this 0.5 m tension is achieved are therefore considerable. The greater the magnitude of the mechanical load applied, the greater the compaction which is likely to occur with compressive failure. Small loads on high shear strength soils may not produce any soil deformation.

Smear is the rearrangement and destruction of soil aggregates due to sliding at the soil/implement or tractor wheel interface. Soils are again most vulnerable to smear when aggregates are weak at high moisture contents (Figure 2). Smear does not occur when soils cease to be plastic, namely at low moisture contents. The greater the load between the sliding surfaces, the wider the range of moisture conditions over which smearing is likely to occur.

Extent of likely soil damage for different soil conditions and operations

Damage due to natural processes is most likely to occur under badly drained conditions. Good drainage encourages natural soil recovery. Similarly the greatest soil damage due to mechanical forces is most likely to occur from working and trafficking at high moisture contents. Smear and local compaction, leading to pan formation, will tend to be greater in soils of high density rather than low. For given loadings, soil density changes due to compaction will be greater, the lower the initial density of the soil. Loose soil conditions are prone to compaction even with small loadings.

Table 1 Relative risk of soil damage resulting from use of different implements

	Nature of soil damage			
Implement	*Smearing*	*Structural breakdown*	*Local compaction*	*General compaction*
Cultivator tines	L		L	
Mouldboard plough share	M		M	
Disc harrow	M	L	M	
Wheel, low pressure		L	L	L
Wheel, high pressure		M	M	M
Wheel, high slip	H	H	H	H

L Low risk M Moderate risk H High risk

Smear and local structural damage occurs at and just below implement working depth and extends across the contact width of the implement. This type of damage and subsequent pan formation, will result from repeated passes at the same depth under moist conditions with all implements, not just the mouldboard plough share and slipping wheel. Table 1 attempts to rank implements and wheels in terms of the chances of smear and structural damage occurring from their use. The high risks from using discs and wheels is clearly shown.

Wheels and soil working components inclined backwards to the direction of travel will tend to produce local or general compaction depending upon the relative magnitude of the applied load and soil shear strength. Implements and wheels are ranked in table 1 according to the compaction risk. Of particular note is the compaction potential of wheels. For a given wheel loading, the higher the contact pressure the greater the degree of compaction likely to arise. The effect of increasing the loading on a wheel while maintaining a constant contact pressure, is to cause compaction throughout a greater depth of soil.

Alleviating and minimising soil damage

Alleviation of soil damage — tillage implications

The prime role of tillage is to alleviate these soil physical problems and if none exist there is little justification for soil cultivation. Tillage operations may therefore be required to modify the existing tilth, relieve compacted and smeared areas or to control trash or weeds, or any combination of these factors.

The depth of tillage required will depend on where the problem is located and this will be dependent on previous management practices and weather patterns. Compaction problems arising from surface operations are usually confined to the top 150 — 250 mm of soil, whereas those combined with rutting and wheeling in the furrow bottom will be considerably deeper. Smeared and locally compacted layers will normally extend to between 20 — 50 mm below the working depth of the implement which caused the problem. Settlement and compaction due to natural processes can extend from the surface to depth of 200 — 300 mm.

Significant savings in energy and time can be achieved by limiting the depth of tillage operations of the minimum possible. Actual implement selection for alleviating the different problems is discussed in other papers.

Minimising soil damage — management implications

It is obvious from the previous discussions that soil damage mainly arises as a result of previous management practices. In addition, if care is not taken during the remedial operations, under certain conditions further problems may be created or the remedial benefits lost before the next crop becomes established. For example on how many occasions is soil loosened only to be immediately recompacted by subsequent wheel traffic? Recompaction may result from either the lifted but non reorientated soil being wheeled back into its original position, or from the traffic compaction associated with the subsequent clod breaking operations necessary to prepare the desired tilth. The major aims in soil management must therefore be not only to avoid or minimise damage but also to ensure any remedial tillage operations are effective for the following crop. To achieve these aims careful consideration needs to be given to the following four major aspects:

a) drainage
b) minimising wheeling effects
c) effective loosening
d) minimising clod and surface level problems.

The major cause of soil damage is wheel compaction and smear under wet soil conditions, thus adequate drainage and control over wheel traffic are essential for good soil management. There are a number of ways through which the effects of wheel traffic can be reduced. These include reducing contact pressures and wheel loads, carrying out fewer passes and combined operations, making greater use of sacrificial areas such as tramlines and haul-roads, and working on undisturbed rather than loosened soil.

Effective loosening and minimal clod and surface level problems are frequently inter-related and apparently sometimes mutually exclusive. Soil clods are usually present in the soil profile before loosening and rather than the loosening implement forming the clods, it simply exposes them to view. If clods are to be exposed, any large clods must be reduced in size before soil loosening rather than afterwards. This can be achieved by working from the soil surface downwards, preparing the seedbed first, rather than from the bottom up; a technique also ideal for effective loosening. Selecting an appropriate spacing for the loosening tines helps ensure complete soil breakout, level soil surfaces for even weathering and minimal smoothing. To prolong the loosening effect, soil rearrangement during loosening is necessary, unless subsequent traffic can be avoided.

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The performance of alternative cultivation systems

D E Patterson

Summary

THE performance of a wide range of alternative cultivation techniques is considered. The results of long term cereal experiments show the savings that can be obtained in costs and energy input with reduced cultivation systems as compared with traditional cultivation, whilst there were no significant differences in crop yield when practised under favourable conditions. Some more recent developments in very shallow surface cultivation are described and preliminary results show that these high output implements are capable of achieving the establishment of large areas of winter cereals.

1. Introduction

CURRENTLY, the farmer is confronted with a greater array of types of cultivation implement and seed drill than at any time in the past. To confuse the issue even further there is renewed interest in deep cultivation for cereals, whilst at the other extreme, direct drilling and "scratch" cultivation systems are in vogue and last, but certainly not least, the traditional plough is still a strong contender. It is not my purpose to recommend one particular technique but on the contrary to present the available data relating to the performance of different systems, so that a choice can be made of those that fit a particular farm, soil type and cropping sequence. The optimum system for a particular set of conditions will generally be the one that gives the maximum crop yield with the least input. The incentive to minimise soil disturbance and numbers of operations is increasing not only due to high wages and fuel costs but perhaps most of all due to the need for timeliness for the more profitable winter cereals. However at present cereal prices, and with the enormous rise in input costs, we cannot afford to sacrifice crop yield.

This paper presents a number of alternative techniques and discusses the main factors influencing choice of system; these include crop yield, system costs, energy requirements and timeliness. Most of the results quoted are from NIAE experiments, particularly long term trials in the period 1971-77 (Patterson *et al* 1980) growing winter wheat on clay loam at Boxworth (B) and on silty loam at Redbourn (R) and spring barley on silty clay loam at Silsoe (S). Reference is made to the main conclusions of results from ADAS (Proctor 1977) and Letcombe (Cannell 1980) experiments.

2. Primary cultivation

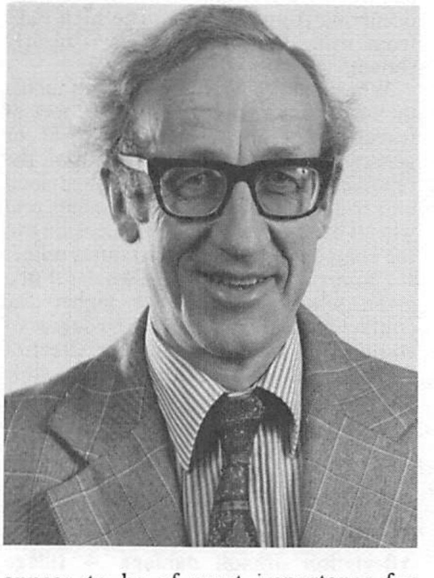
2.1 Medium depth (100 — 200 mm) equipment

In the six years of NIAE experiments growing winter wheat, the main primary cultivation implements were the traditional plough (200 mm depth), the shallow plough (100 mm depth), the chisel plough (fixed tines at 150 mm depth) and the rotary digger (rotor depth 100 mm, tine depth 200 mm).

Throughout the experiments the conventional plough performed at low work rates compared with the chisel plough, shallow plough and rotary digger; the fact that the chisel plough normally required two passes meant that output was intermediate between the plough and shallow plough. The shallower cultivation techniques gave large savings in costs and energy requirements (table 1). The comparisons were made using a 56 kW tractor.

The draught implements performed poorly on wet soils whereas the pto powered rotary digger (Chamen *et al* 1977) led to negligible wheel slip even in the most difficult conditions. Under dry conditions some penetration problems were experienced with the shallow plough and also, when the conventional plough and chisel plough were operated at greater depths (approx 200 mm), a rather cloddy tilth was produced. Fewer secondary cultivations were required following shallow ploughing and rotary digging.

The best degree of inversion was produced with the conventional mouldboard plough but this did not



appear to be of great importance for cereals in the conditions experienced in the experiments. The shallow plough produced a fairly good degree of inversion and the rotary digger was effective on the heavier soils. An additional advantage of the rotary digger is that the three tines behind the implement can be replaced by two sub-soiling tines so that simultaneous shallow cultivation and sub-soiling can be done efficiently.

2.2 Shallow depth (50 — 75 mm) equipment

There are three implements that I want to consider in the category of shallow depth equipment. These are the heavy duty spring tine, the Tillage Train and the Dyna-Drive. All are designed for high speed, shallow depth cultivation (normally about 50 mm) directly on burnt or unburnt stubbles.

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Table 1 Work rates, energy requirements and operating costs of medium depth equipment (mean values over six years)

Implement (using a 56 kW tractor)	Site	*Overall work rate ha/h*	*Net energy* kWh/ha (hph/acre)*	*Total costs** £/ha*
Plough (3 furrow)	B R	0.39 0.62	68 (37) 33 (18)	34.70 22.20
Shallow plough (7 furrow)	B R	0.88 1.12	32 (17) 19 (10)	14.00 11.10
Chisel plough (2 passes, 7 tines)	B R	0.58 0.77	56 (31) 41 (22)	19.50 15.10
Rotary digger (4 years' results)	B R	1.02 1.33	33 (18) 24 (13)	18.60 15.70

* *Energy at the implement connection, not including wheel slip and engine losses.*
** *Machinery, labour and fuel costs, including depreciation based on prices in May 1981.*

Table 2 Work rates and energy requirements of shallow depth equipment (clay loam, one year)

Implement	*Tractor power kW*	*Overall work rate, ha/h*	*Net energy kWh/ha (hph/acre)*
Heavy duty spring tine (3 passes)	56 — 70	0.80 — 1.00	29 (16)
Tillage Train	75 — 105	1.30 — 1.50	22 — 34 (12—19)
Dyna-Drive	70 — 100		

The heavy duty spring tine has become a very popular implement with farmers and in many conditions can produce a satisfactory tilth for winter cereals. Its main disadvantages are the number of passes required, usually three, and the lack of incorporation of any straw or stubble. Additionally, in wet conditions on heavy land it produces long "slithers" of soil which eventually dry out to form clods. In some conditions it is not always possible to operate at very shallow depths due to its tendency to ride out or work too deep.

The Tillage Train and Dyna-Drive are two implements that have been developed through the NIAE scheme for sponsored research and development. Both implements are capable of high outputs so are suitable for those who want to establish a high percentage of their cereal crops in the autumn. The trailed Tillage Train, manufactured by Craven Tasker Limited, Andover, consists of two banks of staggered heavy duty spring tines followed by a set of scalloped disc harrows. Each unit is mounted on sub-frames beneath a heavy duty main frame. The tines are set slightly deeper than the disc harrows and provide the initial penetration and shatter of the stubble whilst helping to pull the disc harrows into work. The discs cut and produce an overall shallow depth of soil tilth across the width of work and help to incorporate any surface trash. High outputs can be achieved (table 2) and a suitable tilth can be obtained in two passes.

The Dyna-Drive manufactured by Bomford and Evershed Limited, Evesham, is a mounted unit consisting of two soil-driven rotors linked by a chain drive. The particular design overcomes the two "power-wasting" features of existing powered cultivators:—

a) high tine speed through the soil which leads to high power consumption
b) unfavourable angle of entry into the soil ie trying to break the soil by cutting downwards or sideways, instead of upwards.

The implement consists of a horizontal axis rotor revolving slowly in relation to the forward speed and carrying tines angled so that they penetrate the soil at a shallow, upward lifting angle. The torque from the front rotor is transmitted to the ground through a second rotor which both reduces total power requirement and effects surface cultivation. Normally, two passes are required and high outputs can be achieved. The machine has good self-cleaning characteristics in trashy conditions although straw tends to be left on the surface. A feature of the machine is good penetration under hard dry conditions.

3. Secondary cultivation

In the six years of NIAE cultivation experiments the spring tine cultivator and disc harrow were particularly suited to the lighter soils or preparing a seed bed on the heavier soils where a degree of weathering had occurred. The disc harrow was effectively used to incorporate straw on some non-ploughed treatments. A finger tine harrow had particular application on the heavy soils in the spring where it was important not to bring up unweathered wet soil from beneath the surface.

The pto driven rotary harrow and spiked rotary cultivator were suitable for producing a tilth for a winter cereal seed bed from cloddy soil and weed conditions.

4. Combined operations

4.1 Link for powered and draught implements

A number of designs of bridge link for combined secondary cultivation and drilling are now available commercially (Patterson *et al* 1981). The Boyden link, manufactured by B & W Boyden Limited, Peterborough, and based on the NIAE design is intended primarily for operation on ground that has already been cultivated. The link passes from the drawbar of the tractor to a rigid connection on the seed drill and is designed so that the tractor three-point linkage can be used for both power take-off driven and draught implements. Roll and pitch swivels are located at the draw bar which ensures stability, even on sloping land.

The use of combined cultivation and drilling equipment has enabled a greater proportion of tractor power potential to be used at a similar energy level (table 3). On the heavier soils it is necessary in some years to use power-driven tools to obtain a suitable seed bed and on these occasions the work rate of the combination will be reduced to the output of the powered tool. Simple draught implements are satisfactory on lighter soils and also in the spring when the effects of over-wintering have produced good weathering after the primary cultivation. Both power-driven and draught implements when used in combination with the drill give a considerable overall saving (approximately 35%) in labour requirements.

Whilst at the autumn sites in NIAE experiments at Boxworth and Redbourn there have been no difficulties using combined secondary cultivation and drilling implements, separate cultivation and drilling operations had to be carried out on heavy clay soil in the wet years of 1971 and 1976 at the spring barley site. The soil at this site was slow to dry out and it was necessary to cultivate the soil in a separate pass to assist drying and allow passage of the drill.

4.2 Pressure link for draught implements

When bridge links are used with existing power driven equipment overall workrate may be limited by the output of the powered implement. In 1978 it was decided to examine the merits of a bridge link mechanism constructed for use with draught implements only, but with the facility of a double acting ram for transferring weight onto the cultivation implement when used on cereal stubble. It is also fitted with rubber suspension units to enable the implement to follow ground undulations. When used with a disc harrow on cereal stubble, soil disturbance and straw incorporation has been better than existing designs of direct drill. Preliminary trials on farms and in plot experiments have given savings in costs and fuel requirements without any reduction in yield.

Trials with the link on ploughed land in Hampshire indicated that some "plumbing up" of soil occurred between tractor wheelings, where wheels had not consolidated the ploughing. A drawbar equipped with 3 wheels on the bridge link has successfully reduced the uneven effect of wheelings by providing consolidation between the tractor wheels. Mr J Turner of Basingstoke, the farmer who suggested the modification, has obtained more even stands of cereal plants in his first year of using this equipment.

The link can be simply and quickly disconnected from the drill, so that discing can be carried out separately, if required, and then re-linked to the drill for simultaneous cultivation and drilling in the second operation. Hence the unit

Table 3 Mean energy and labour requirements for separate and combined operations, 1971-77

Implements used after ploughing	*Site*	*Net energy kWh/ha*	*Labour man h/ha*
Cultivator + drill	B	21	1.4
Combined cultivator/drill	B	22	0.8
Cultivator + drill	R	17	1.0
Combined cultivator/drill	R	17	0.7

Table 4 Labour requirements, costs, energy requirements, and area capability for cultivation systems.

Cultivation system	*No of years*	*Site*	*Depth of primary cultivation, mm*	*Labour requirement, man h/ha*	*Net* energy kWh/ha (hph/acre)*	*Cost** £/ha*	*Area capability ha*****
Plough, cultivator,	6	B	220	4.0	89 (48)	67.20	88
drill	6	R	220	2.6	50 (27)	43.60	132
Chisel plough, (2 passes),	6	B	130	3.3	79 (43)	50.10	107
cultivator, drill	6	R	145	2.4	54 (29)	36.80	142
Shallow plough, combined cultivator/	6	B	110	2.0	52 (28)	32.40	178
drill	6	R	105	1.6	30 (16)	26.10	214
Rotary digger, combined cultivator/	4	B	100/200	1.8	49 (26)	35.20	197
drill	4	R	100/200	1.4	40 (22)	30.00	235
Sprayer	5	B	—	1.0	11 (6)	49.50	353
direct drill	4	R	—	0.9	12 (6)	38.90	368
H D Spring Tine (3 passes), Drill	1	Clay*** loam	50-75	38 (20)	27.30	180	
Tillage train or Dyna-Drive (2 passes) Drill	1	Clay*** loam	50-75	1.4-1.5	27-39 (15-21)	22-28	210-260

* *Energy at the implement connection.* ** *Machinery, labour and fuel costs, including depreciation based on May 1981 prices.*
***Clay loam soil similar to Boxworth site.*
**** *Area capability is calculated from implement work rate and hours available between beginning of September and end of October (Boxworth 360 hours).*

can be adapted to suit the requirements of individual conditions.

5. Performance of cultivation systems

5.1 Timeliness, costs and energy requirements

The results for different systems in terms of labour, energy requirements, costs and area capability are summarised in table 4. The main trend is the major savings in labour, energy requirements and costs that can be obtained by reducing depth of work and combining implements to reduce the number of passes.

Burning straw and/or stubble was found to be fundamental to the success of established direct drilling techniques and it reduced the problems of reduced cultivation systems. More recent experiments have shown that a good burn has enabled the establishment of a satisfactory seed bed with just one pass with the Tillage Train or Dyna-Drive prior to drilling. More recent designs of direct drill including the Moore Uni-drill, the Tasker drill and the SIAE "A" blade coulter, incorporate devices to move the straw away from the seed slit. The main advantages in burning appear to be a reduction in viable volunteer cereal and weed seeds, increased crop yield, fewer mechanical problems at drilling and a saving in time and labour. Similar results have been obtained in ADAS experiments on different EHFs (J Oliphant 1981).

The main advantage of direct drilling is the high work rates (table 4) possible for both spraying and drilling, which enables a very large area to be covered by one man and tractor. Whilst in many conditions performance is satisfactory, the direct drill used in the experiments was restricted by wet soil conditions, particularly on heavy soil for spring barley; an uneven stubble surface, the presence of cereal stubble or chopped straw and a lack of tilth under hard and dry soil conditions. Costs for direct drilling were generally higher than the best reduced cultivations but this depended on the dilution of spray material and frequency of use.

In initial trials the Tillage Train and Dyna-Drive have given high outputs at low costs per hectare.

5.2 Crop yields

The results from the NIAE experiments are given in table 5. When considering overall crop yields for a period of years the only treatment which was significantly lower than mouldboard ploughing was direct drilling at Rothamsted and Silsoe. The main reasons for this were the restrictions described earlier.

The 1973/74 season produced unexpected results at Boxworth where the yields from most of the treatments were significantly lower than mouldboard ploughing this may have been due to extensive crop lodging on non-ploughed plots. In the very dry year of 1975/76 the direct drilling and rotary dug plots produced a significantly higher yields than mouldboard ploughing at Boxworth due probably to a greater conservation of moisture.

Results from experiments (Cannell *et al* 1980, Proctor 1979) and the experience of farmers show that shallow tillage and direct drilling can be successfully used for cereals on naturally well drained and structured chalk and limestone soils, and loams; and for winter cereals on clay soils that have been artificially drained. However, there is substantial risk of lower yields than from conventional cultivation on sandy soils with low organic matter content, silty soils, and many wet alluvial and clay soils.

6. Conclusions

6.1 The traditional plough is most suitable where maximum crop residue burial and good weed control are required and if high output is not an important factor. Subsequently on the heavier soils a large number of secondary cultivations are required to obtain a suitable tilth. In many situations consistently high crop yields can be obtained compared with other systems sown on the same date.

6.2 The shallow plough operating at a depth of approximately 100 mm provides nearly double the output of the traditional plough, whilst costs and energy requirements are much lower. Crop residue inversion and burial is good so weed control is satisfactory. The shallow plough will not penetrate adequately under vey hard conditions.

6.3 The output of the rotary digger is nearly twice that of the traditional plough and this power-driven tool is suitable for the establishment of a wide range of crops including cereals and roots. Seedbeds for cereals can be prepared from cereal stubble, grass or following a crop of roots. The digger can be operated in a wide range of soil conditions ranging from wet/soft to hard/dry and will provide a better degree of inversion than two passes with a chisel plough. On heavy land it will incorporate cereal stubble very satisfactorily, but it is important to carry out a

Table 5 Crop yields (tonne/ha, 85% dry matter)

Cultivation system	*Site*	*Mean for 4 yr 1974–77*	*Mean for 6 yr 1972–77*
Plough, Cultivator, Drill	B	5.77	6.02
	R	5.21	4.97
	S	5.52	5.18
Plough, Combined cult/ Drill	B	5.65	5.94
	R	5.04	4.83
	S	5.62	5.18
Chisel plough (2 passes) Cultivator, Drill	B	5.65	5.90
	R	5.00	4.85
	S	5.54	5.23
Shallow plough, Combined cult/ Drill	B	5.62	5.87
	R	5.03	4.76
	S	5.70	5.32
NIAE Combined cult/ Drill	B	5.57	
	R	4.97	
	S	5.71	
Sprayer, Direct Drill	B	5.72	
	R	*4.52*	
	S	*4.53*	
SE (standard error)	B	0.06	0.13
	R	0.12	0.11
	S	0.1	0.11

secondary cultivation soon after the primary operation to reduce the risk of hard dry clods.

6.4 Chisel ploughing techniques (fixed tines at 150 mm and heavy spring tines at 50 mm) normally require more passes over the ground than other systems but energy and costs are still lower than ploughing, particularly in the case of the shallow tines. Because of a general lack of incorporation, more spraying is often required to achieve adequate weed control.

6.5 Bridge links allow flexibility of use of different secondary cultivation implements with a drill and provide substantial savings in labour requirement with fewer tractor wheelings. The latest design which provides high vertical loading onto a disc harrow is very suited to working on ploughing or previously cultivated land and also for operation directly on cereal stubble as a direct drill. If required the disc harrow can be used separately for a shallow cultivation and then reconnected to the drill for the second pass.

6.6 Very high work rates can be obtained with direct drilling systems so such techniques are particularly suited to large areas of winter wheat (Cannell *et al* 1978) where speed of operation is vital to ensure timeliness. Good stubble burns are generally essential to the success of this technique with existing designs of direct drill. New designs such as the Moore, Tasker and SIAE "A" blade drills may be suitable where straw is present on the surface.

There are risks attached to direct drill techniques, particularly on poorly drained and the self-compacting soils. On these soils some form of regular sub-soiling may be required. Great care in management is necessary to control weeds.

6.7 Many farmers are experimenting with shallow surface cultivation after harvest. There are now available a number of high speed techniques, including the Tillage Train and Dyna-Drive, which prepare a good seed bed in one or two passes. Such systems are flexible, as they encourage early weed germination and allow use of a conventional drill instead of a direct drill. On poorly drained soils consideration needs to be given to deeper loosening. Such loosening may consist of an operation at depths of only 150-200 mm to ensure drainage of water away from the surface region.

6.8 For a further extension of the use of shallow cultivation techniques and direct drilling, consideration will need to be given to ways of reducing compaction, not only from tractors but also from combine harvesters and trailers.

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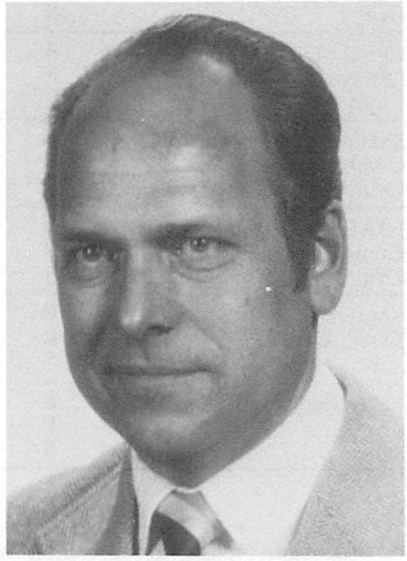
The role of the mouldboard plough?

H Traulsen

Summary

THE mouldboard plough determines the tractor force required on a farm, takes a lot of good skilled labour, but does not mix soil very well. So for many years the rotary cultivator, the heavy cultivator and the direct drill have been used. Nevertheless, trials in Germany show that the plough should not be discarded. On normal soils one can do without the plough for one or two years. But in the long term we see disadvantages with regard to weed control, yield loss, trash disposal and herbicide costs.

There have been several attempts to improve the mouldboard plough, eg the diamond plough and slatted bodies. The system comprising heavy stubble cultivator, reversible plough with furrow press and immediately behind rotary harrow with drill is very famous and successful on medium and heavy land. One must not be dogmatic about the use of the plough because many factors, ie climate, soil type, crop and season, are factors which affect its utilisation.



Introduction

Soil tillage is a very fine subject for discussion as every soil and climate is different, as are the conditions on every farm. But what is most important is that you can only see the results of different forms of tillage after a number of years. There are many other factors that are important. A bad implement and a good farmer may give a better result than a good tool in the wrong hands. On most farms the plough determines the size of the biggest tractor. Most field trials on minimum cultivation in our country are about ten years old. The results were not bad and the advisers were quite content. Not so today. Several advisers recommended abandoning the plough some years ago, but say the opposite today.

When discussing the problem we often think of extreme situations. To plough a high moisture soil and a thick straw matt into the ground is as wrong as to do without the plough year after year on a mild loam soil in an intensive cereal sequence.

There are many field trials that show similar or even better results when practising minimum tillage, and lots of them show the opposite. In our pretty wet climate, as in your country, official tests show better yields when the land has been ploughed. But I think it is not sensible for me to quote long lists of trial results. The results are so variable that one should discuss the yields in the trial field, not in a hall.

On very light sandy soil in Schuby, Schleswig-Holstein, there have been trials for minimum tillage since 1968. Though the opinion of the official consultants were reserved and they would not recommend this in general, the average spring barley yields were not bad.

Dr H Traulsen, Head of Department of Agricultural Engineering and Farm Buildings, Chamber of Agriculture, Schleswig-Holstein, West Germany.

Table 2 Field trials Schuby 1968 — 1980 Spring barley (Landwirtschaftskammer Schleswig-Holstein)

	tonne/ha	%
Minimum tillage	3.054	107
Conventional tillage (Plough, seed bed combination)	2.857	100

What is much more important than the actual yield is an answer to the questions why these different results? What may be the reason that enthusiastic farmers and advisers changed their mind and turned to the plough again?

Some reasons are:—

1. Weed control is often a problem after some years.
2. Foot diseases arise, when the seedbed is not "clean".
3. Cereal yields have increased very rapidly in recent years. More straw has to be tilled in the soil.
4. Minimum cultivation works well with a mixed rotation. But the proportion of cereals has increased in recent years, 75% being normal. In a rotation wheat, wheat, barley, rape, one might do without the plough after the rape. Shed cereals can be a big problem.
5. All cereals in our country are normally autumn crops. The growth period is often almost one year or even more. Therefore there is little time for climatic factors such as sun, rain, wind and so on to produce a good seed bed. Soil tillage has to be short and intensive.
6. Slugs have become a problem with minimum cultivation.
7. Root weeds can become at least a financial problem, which the plough solves more easily and cheaply without environmental problems.
8. The performance demanded of drills has risen and hence better seedbeds are required.
9. Modern cereal varieties have more roots and therefore are less suitable for minimum tillage.

What might be different in your country compared with Schleswig-Holstein? The climate, temperature and rain are comparable, but probably opinions regarding the right tillage system are different. The price for herbicides is much cheaper in the UK and you grow dwarf types that are more suited to minimum tillage.

Soil fertility

There is no better way to cut costs than to

Table 1 Yield with a heavy cultivator (%) compared with a plough (100%) (Koller, W-Germany)

Autumn wheat% *Autumn barley %*	*101* *95*	*97* *98*	*101* *97*	*102* *100*	*101* *98*	— *86*
	Hoffman Oldenburgh 1974	Zach Volken-rode 1975	Patter-son England 1973	Koller Hohen-heim 1975	Golisch Ronnen-berg 1975	Teuteberg Kiel (Schuby) (1968-1977)

save an expense. Minimum tillage therefore is very evident. But the plough not only has the job of preparing a good seed bed, it also has to guarantee good long term soil fertility. So all cost saving comparisons should be made long term as well, which of course is very difficult in practice. Almost always the problems with tillage without the plough increase with the years. Therefore short term results are of little consequence.

Monoculture

Special considerations must be made when just one crop is grown. In monocrop growing, minimum tillage in our country was almost as good as conventional tillage. The water capacity increased and was not disturbed, there was almost no erosion. The nutrient concentration increased in the rooting zone as one grassland. Hence minimum tillage brings advantages similar to those which results from mixed cropping. Nevertheless over ten years, mixed cropping shows an advantage of approximately 0.1 tonne/ha.

Ploughing depth

One can reduce fuel consumption by 12-15% if ploughing depth is reduced by 50 mm. But better yields in recent years resulted from, among other things, the ability to plough 100 mm deeper as a result of the availability of larger tractors and better knowledge of subsequent treatments. More nutrients have to be given if they are not already in the soil as a result of high residual levels. Furrow bottom smearing was more of a problem with small tractors when shallow ploughing with much wheel slip. More powerful tractors with better tyres do not slip so much though they are lighter per kW. For a nominal ploughing depth of about 300 or 400 mm it is usual for the actual depth to change much more than it does for a depth of 150 — 200 mm, especially as shallow ploughing is recommended in wet years. The impedence of water at the furrow bottom, as feared in former times, is no longer a problem as a result of deeper ploughing. Water capacity increased and Teuteberg said that 0.5 — 0.6 tonne/ha better yields might results from deeper ploughing. In the average of 4 years he found the following yields:

Table 3 Yield of Autumn wheat (average four years, %) (Landwirtschaftskammer Schleswig-Holstein)

Plough depth	*tonne/ha*	*%*
180 mm	6.56	100
250 mm	6.79	104
320 mm	6.80	104
rotary cultivator 100 mm	6.06	92.5

In rape the differences are lower because the roots have greater ability to penetrate the subsoil.

Field tests on the Brandhof in 1967 — 1969 showed in each case better pore volumes of 5 — 8% for the ploughed land compared with direct drilling. *Cercosporella* (Eyespot) and *Ophiobolus* (Take-all) were 21 — 154% greater in the minimum tillage area.

The role of the plough

Before we ask what other implements could do the job of the plough, we have to define the role which the mouldboard plough performs: ie loosen, turn, crumble, destroy weeds.

What it does not do well is mix. The plough always needs a following operation. On heavy land large clods are a problem. The plough requires good skilled labour by contrast with cultivators or harrows. The plough supports soil erosions. There have been many attempts to alter the mouldboard plough but the rotary plough, the disc plough and the spading machine did inferior jobs, used more fuel or were not reliable enough. Of current interest are:—

Diamond plough (Huard, Massey Ferguson)
The diamond plough is a type of mouldboard plough, that came from France which has been discussed very intensively in our country for some time. Of the several theoretical advantages the real facts are:

a) The diamond plough is easier to pull at least up to 8 km/h and at plough depths over approximately 250 mm.
b) The diamond plough might use less fuel, but experiences of the researchers are contradictory.
c) The diamond plough gives a wider furrow for big tyres, it is shorter and therefore should be easier to lift hydraulically.

But in practice you will find this type of plough in very few areas. The plough is expensive — in many parts costing double — most types are very heavy so that they are as hard to lift hydraulically as the normal plough. Import results from our field tests showed that the diamond plough leaves a rough furrow and that the fuel that might be saved by the plough is needed to prepare a comparable seed bed. This confirms that in soil tillage nothing is free. For a certain tilling effect you need a certain amount of horsepower and fuel. It is the same with plough body type. Our general purpose body requires more energy than some Scandinavian types, but the first crumbles better.

Slatted bodies

Of real interest at the moment is the plough with slatted bodies which has been available in the States for many years. Almost all plough manufactures now build this type. All parties agree that this type has advantage on sticky soil. But it is recommended on all soils as it should be easier to pull. Our first field trials on sandy loam and clay cannot confirm this. There was no significant difference.

Push ploughs

We have also looked at the French 'Push plough'. We tested this on the same sandy loamy field. With the same tractor (Deutz DX 145 [98 kW]) the semi mounted, 7 furrow plough from Lemken was slightly better than the push plough from Naud with 3 furrows in front, 4 at the back (Table 4).

It must be stated that we have only subjected this plough to two tests in the field. They have to be continued.

These new types of plough can be improved, but so can the conventional mouldboard plough. Draught may be

Table 4 Plough test, push plough 1981

Type	*Lemken semi mounted*	*Naud push ploughed*
Width	2.904	2.949
Depth (mm)	278	272
Speed (km/h)	5.54	5.53
Slip (%)	20.3	18.9
Fuel consumption per soil volume (ml/m³)	6.19	6.05
Specific power requirement (m³/min/kW)	0.766	0.685

Table 5 Labour (hours/ha) and fuel consumption (Köller 1981)

System	*Soil* "light" h/ha	rel	l/ha	"medium" h/ha	rel	l/ha	"heavy" h/ha	rel	l/ha
Plough + seedbed-combination + drill	2.07	133	50	2.45	127	61	3.42	123	88
Plough + rotary harrow/drill	1.56	*100*	44	1.93	*100*	54	2.77	*100*	78
Cultivatory + rotary harrow/drill	0.97	62	27	1.16	60	33	1.28	46	36

reduced by up to 10% when ploughs are set correctly. Friction is reduced where mouldboards are covered by plastic or Teflon; even micro waves and water have been tried.

Alternatives to the plough

The most discussed substitute for the plough is the heavy cultivator. We do not recommend the chisel plough as it is too specialised. But the rigid tine cultivator on heavy land (with a break back mechanism) and the heavy spring tine cultivator on light land, in each case with double heart shares, are satisfactory. These types do a good stubble job and can work as deep as the plough. But as explained before we do not think that the heavy cutlivator can replace the plough on normal soil for long periods.

Apart from this the heavy cultivators are preferred on stubbles. Here the normal plough does a bad job. The skim plough is too special, and still needs a following operation.

In our country the best implement to replace the plough might be the rotary cultivator. But in general, seed beds and yields are better when the Lely Roterra is used on ploughed land.

We in Schleswig-Holstein are proud of our high cereal yields which are similar to yours in eastern counties. Figure 1 shows the yields of the last ten years Top farms in Schelswig-Holstein harvest above 10.0 tonne/ha. But we have to do much to achieve such results. For the best results perfection is required. As far as we know good seedbed preparation is a fundamental requirement.

Let us say that you can save 10 litres fuel/ha by using a heavy cultivator instead of a plough, and 20 kg/ha nitrogen because of the better mixed organic material. Further, less skilled workers can do the job. Although the system in which the plough is used might cost 20 — 40 DM/ha more (£4.50 — 9.00) equivalent to a yield increase of 50 — 100 kg/ha. In many cases, especially with wheat, the plough will guarantee this improvement. When these economic factors are considered in conjunction with the high risk of more weeds, especially perennials, and slugs etc, it can be seen why the plough has not been condemned.

One could be less dependent upon the plough given:—

- light or very heavy soil
- few weeds, especially perennials
- good soil structure
- high fertility status

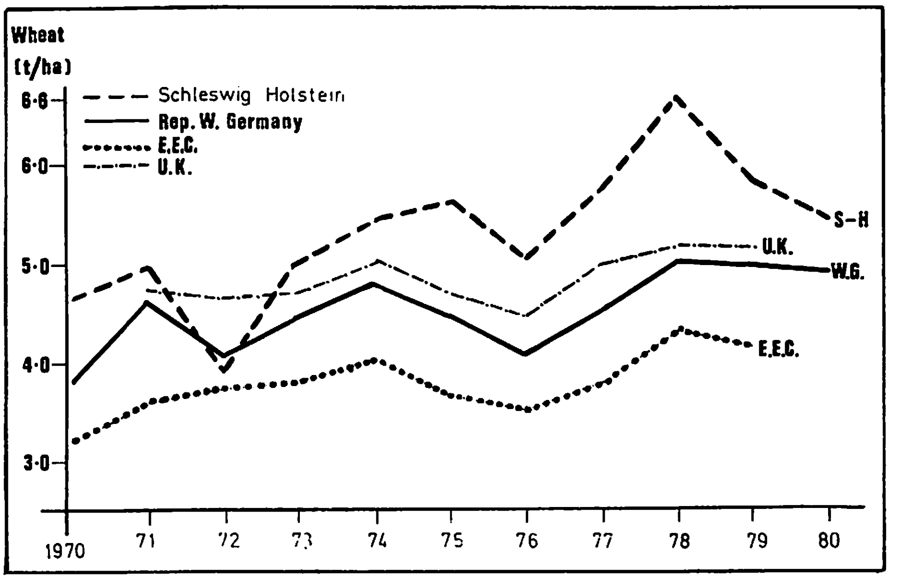


Fig 1

A very important point is that the specific conditions in each year have to be checked before deciding upon the cultivation system to use. We have a farmer in West Germany who is very famous for his ploughless farming. Coach loads of farmers visited him and many copied his methods. In an extremely wet year it was a disaster and many asked how this farmer had managed? He ploughed.

On loamy soils that are ploughed too dry or too wet in 70 — 80% of the years it may be an advantage to only plough in alternate years. On peat soils the material is oxidised too much when ploughing each year.

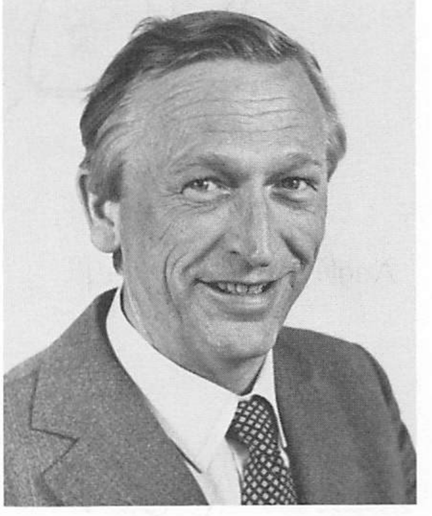
All these results and observations led to the development of a tillage system (Bestellsaat) which originated in Holland and was first introduced in the clay areas near the coasts. Now that rotary harrows are available which can operate under stoney conditions the system has spread over the whole country. The system we recommend at the present is to first cultivate stubbles with one or two passes of a rigid tine cultivator as soon as possible after harvest. Then plough just before drilling preferably with a reversible plough followed by a furrow press. As soon as possible after this there follows a rotary harrow combined with a drill. Though few field trials have been carried out, this system seems to increase yields by about 5 — 7% compared with conventional methods because of fewer wheelings in the field, low weather risk, good water supply, drilling more slowly and so on.

Conclusion

The conclusion of many discussions might be that a modern farmer should not use implements which came from the ark and require at least 10% more fuel than other systems. But 10 — 20 years experience of the rotary cultivator and the heavy cultivator did not convince us that we can do without the plough in general. It inverts better than other soil implements and can bury large quantities of organic matter. But one must not be dogmatic about the plough. Under certain conditions, after some crops, labour and costs may be saved if the plough is not used, resulting in similar or higher yields. There has been a distinct change in tillage systems in our country in recent years to the use of reversible plough, furrow press and rotary harrow combined with a drill. But despite many field trials there is no move from the plough to the direct drill or other cultivation systems, and not only because ploughed land looks nicer.

The role of discs in primary cultivation

J B Finney



Introduction

TILLAGE research workers have for many years pointed out that cultivations for cereals need not exceed 100 mm depth under many conditions (Russell & Keen, 1941) and that there may be positive advantages in only disturbing the soil to seeding depth (Cannell, 1979). Where this applies the farmer, aiming to plant his winter cereals over a very short period of late September and early October, might be looking for an implement which would completely disturb the soil to a shallow depth in one pass, with a low energy requirement and high work rate and long intervals between repairs or parts replacements. Heavy duty disc harrows apparently fulfil these requirements.

Agronomic evidence on the performance of discs

FARMING tradition suggests that discs should not be treated as universal cultivation implements. The advice of experienced cultivators has been to avoid discs if a tined implement will give the required effect. This generally means avoiding discs if the soil is moist enough to be friable. Cases of compaction apparently caused by discs are regularly brought to the notice of advisers and, since they rely on weight for penetration, this might be expected. There is, however, little actual data on the amount of compaction or how it is produced and no clear crop-yield evidence from agronomic trials. Below a certain disc angle (fig 1) the back or convex side of the disc exerts what can be a substantial compressive force on the soil and the cutting edge also exerts a compressive force which may be reduced by sharpening the concave rather than the usual convex side of the disc.

McCreery & Nichols (1956) quote work published in 1940 where the roots of cotton plants did not penetrate appreciably below tillage depth on plots prepared with disc implements. Browning & Norton (1947) reported on yields of maize from 52 fields over the period 1944/46 when discs gave the lowest average yield compared with the mouldboard plough and other systems, with the stated reason that weed control was poor when discs were used. They suggested that discs were only suitable for primary cultivation where the previous crop left the soil in a loose and friable condition. Cook & Peckert (1950) compared yields of oats, beans, maize and beet on a range of soil textures after discing to 150 mm depth with conventional plough systems. Yields were not lower, even when primary and secondary treatments were with discs. Barker (1963) in a series of experiments on primary cultivation used light tandem discs to produce a tilth 25 — 50 mm deep, which required up to 6 passes after a ley, whereas the aimed depth was exceeded (to 75 — 100 mm depth) in one pass after roots. There was some evidence of restricted root growth in kale after discs, but Barker suggests in a private communication that any yield differences found could be accounted for by weeds rather than deterioration of soil physical conditions.

More recent agronomic work with discs has been carried out with the benefit of modern herbicides. In this country Patterson (1980) included discs in several forms in a series of experiments on economy in cultivations for cereals when crop yields were not significantly different from those produced under alternative systems of cultivation. Where there were slight yield depressions the difference could possibly have been attributed to other elements in the cultivation system. From elsewhere in the world there are reports of discs producing positively increased yields. For example, Sheikh *et al* (1980) quote improved crop emergence and yield for discs compared with tine and North American type sweep cultivators. Crop yield evidence does not clearly confirm or deny the opinion of many farmers, research workers and advisers, that as a primary tillage tool, discs reduce compactness to the depth of operation, but can compact the soil immediately below that level (Cooper, 1971). The sensible practical approach would be to exercise caution where soil is known to be compacted to some extent before cultivation and even greater caution under compacted and wet conditions.

Discs available in the United Kingdom

Tilted discs

These are individually mounted out of the vertical and are adjustable to the vertical and for the angle of the face of the disc to the direction of travel (the disc angle). This arrangement is used only on disc ploughs and is not represented among the equipment normally used for primary cultivation in Britain (fig 1).

Vertical discs

Vertical discs can be angled only to the direction of travel and numbers of discs are grouped on one axle. The angle available ranges from 0° to 30° on tandem and offset implements designed for both primary and secondary cultivation, to 35-60° on vertical disc ploughs.

Disc shape is generally concave, but may be conical, a shape said to require less force for penetration; or convex centre, which is said to give more soil inversion (fig 2).

Vertical discs are available in three main forms:—

Single Acting — a single row of discs operated at 35-60° to the line of travel.

Offset — two straight rows of discs, angled to give up to 30° disc angle. They get their name from the ease with which they can be operated offset from the centre line of the tractor.

Tandem or double offset — two rows of discs which can be angled from the centre of each row. This is the design most commonly used for shallow primary cultivation (fig 3).

Discs for primary cultivation are generally 610 mm (24 in) or 660 mm (26 in) diameter and carry weight in the range 75 — 135 kg/disc. For secondary cultivation, diameters of 500 mm (20 in) or less may be used with weights as low as 25 kg/disc. Disc spacing is generally of the order of 230 mm (9 in). Wider spacing gives better penetration and clearance, while narrower spacings give better pulverisation and more uniform soil disturbance. Some tandem discs use front gang spacing of the order of 270 mm (11 in) against 230 mm (9 in) at the rear to combine the advantages of both arrangements.

Individual discs may be plain or of the cut-away or scalloped type. The latter penetrate better than plain discs and more effectively cut through trash. Plain discs give better pulverisation and covering. For primary work, scalloped discs at the front and plain discs at the rear are often favoured by farmers. In

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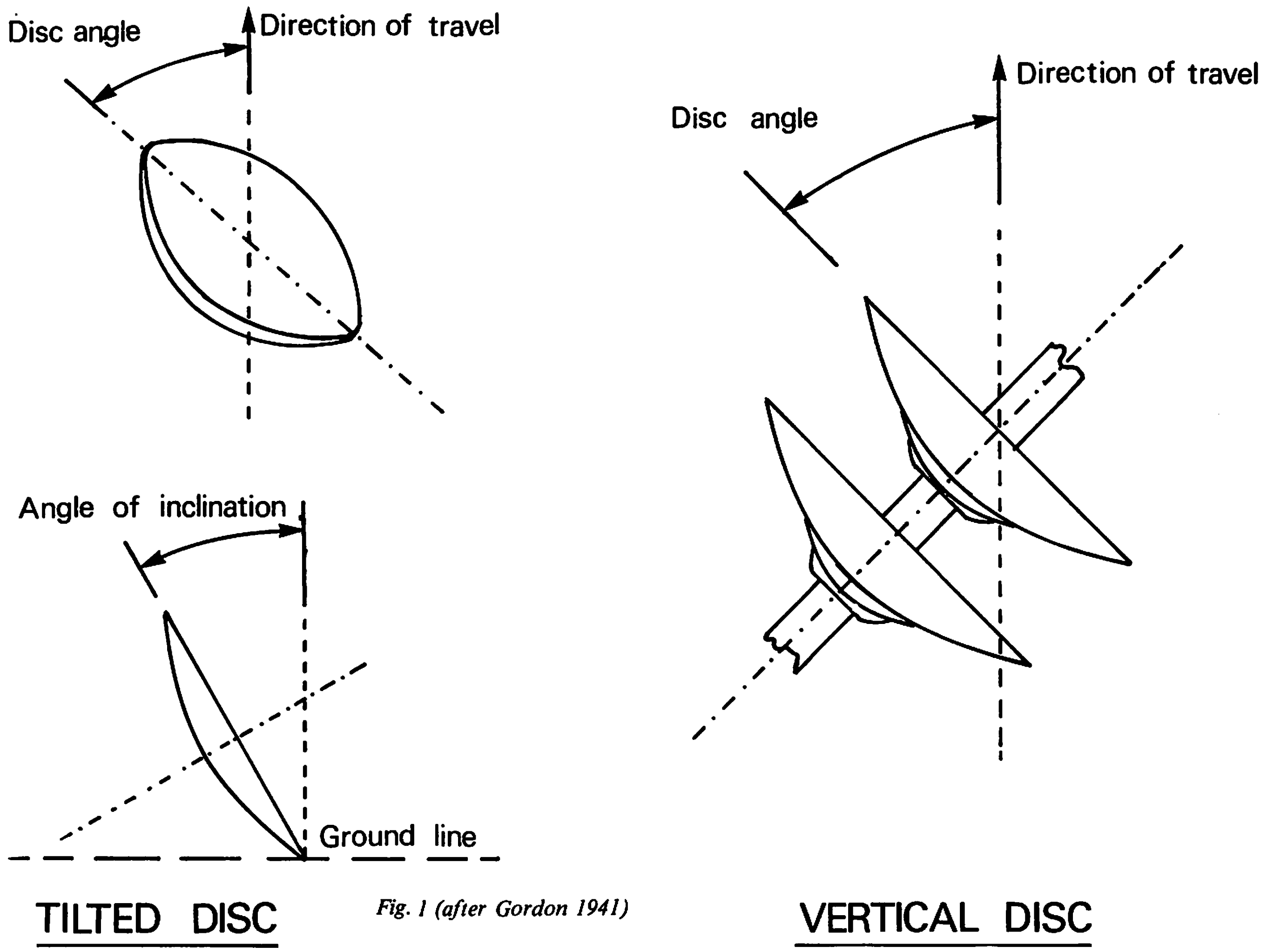


Fig. 1 (after Gordon 1941)

Fig. 2 Disc shapes

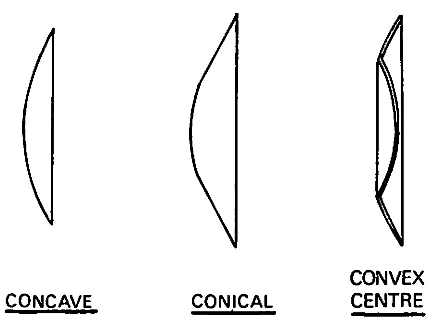
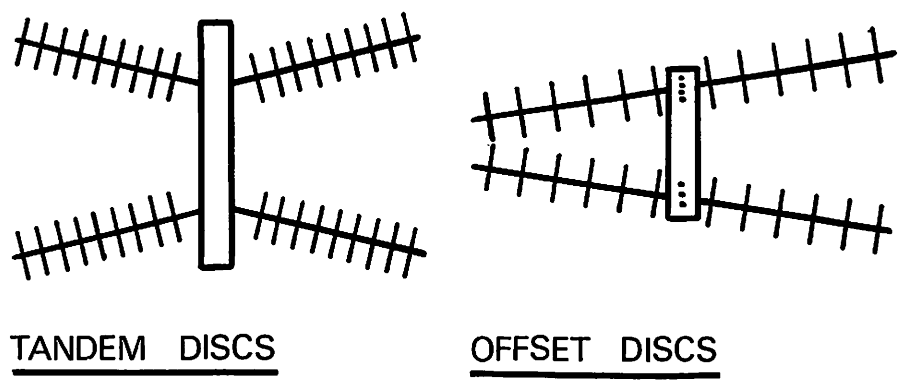


Fig. 3 Disc configuration



districts where soils are abrasive and wear is a problem, plain discs are often used at the front with scalloped discs at the rear. All plain and all scalloped combinations are also used.

Uniform penetration is difficult to achieve with discs. Individual gangs tend to rise high at the convex end and low at the concave end, so that the tendency is for the centre of the divided front row to ride out and similarly the outer ends of the rear row. Provision is usually made in the design of equipment to deal with this problem and similarly drawbar adjustments are provided to cope with front-to-back levelling.

Rigidly constructed implements, when correctly level, act as good soil levellers but do not give uniform cultivation depth where there is any undulation of soil surface. Flexible mountings, generally provided by a spring arrangement, are more likely to result in uniform depth of working.

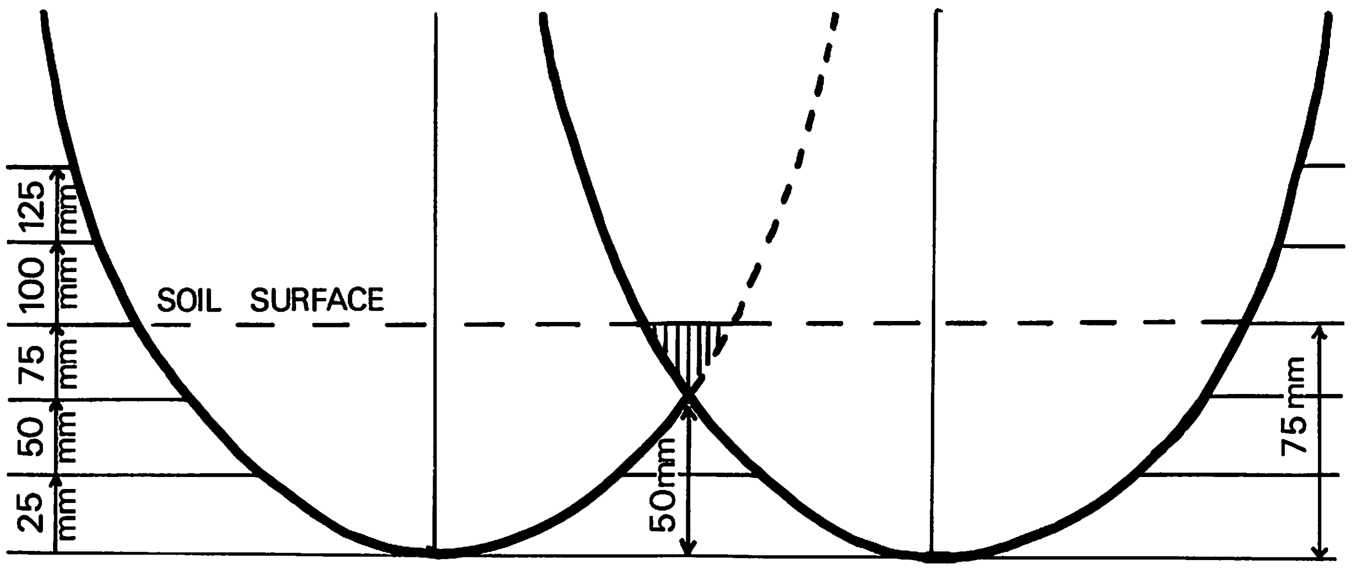
Soil is moved either to the right or left by each gang of the set of discs. The soil thrown out by the front discs is often levelled by a smaller diameter out-rigger or erasing disc at each end of the second gang. A central tine can be used to take out the ridge that may form between the gangs.

In some cases rear discs of greater concavity (smaller radius of curvature) have been used to give improved levelling effect.

The practical operating points worth noting are:—

a) Penetration can be improved by adding weight, reducing forward speed, using smaller diameter, scalloped or wider spaced discs and by increasing the disc angle.
b) Uniformity of depth of working can be improved with larger diameter discs, non-rigid mounting and closer disc spacing.
c) Pulverisation and covering can be improved by increasing forward speed, using plain discs and narrowe disc spacing.
d) Choking can be reduced by wider disc spacing, larger diameter, increased forward speed and reduced disc angle.

Fig 4 Disc cuts (after Thompson 1958)



610mm disc, 30°angle, 200mm spacing

Extent of soil disturbance

The introduction to this paper suggests that the commercial requirement is for an implement which will completely disturb the soil to a shallow depth in one pass. The extent to which this can be achieved depends on disc diameter and angle and has been described graphically by Thompson & Kemp (1958). Using 460, 510 and 610 mm discs (18, 20 and 24 in) at 75 mm depth (approx the depth at which Patterson worked in his experiments) and 30° disc angle, total soil disturbance to at least 25 mm is achieved at 150, 180 and 200 mm disc spacing (6, 7 and 8 in). Commercial two gang implements with individual spacing at about 230 mm and available disc angle up to or near 30° therefore have the potential for satisfactory one pass seedbed preparation (fig 4).

Single acting or single gang discs, with their greater disc angle adjustment, can achieve the same result at wider spacing. For example, the 610 mm (24 in) disc at 40° would give this degree of disturbance at 250 mm (10 in) spacing.

Energy requirement and work rate

Wismer & Luth suggest that a simple rolling resistance coefficient of 1.5, 1.2 and 0.8 for heavy, medium and light soils respectively, would be an adequate estimate of implement draught at any speed. This suggests a heavy tandem disc draught in the range 5.0 to 8.7 kN/m of implement width for the lighter soils, rising to 9.4 — 16.2 kN/m on the heavy soils. This corresponds approximately with Patterson's figures in the range 61 — 115 MJ/ha (1 kN/m width draught is equivalent to 10 MJ/ha energy input). The figures suggested by Hunt (1977) for heavy tandem discs indicate only half the energy input so far round to be necessary in Britain and are unlikely to be of value.

DISC BEARING AND PRESSURE AREA

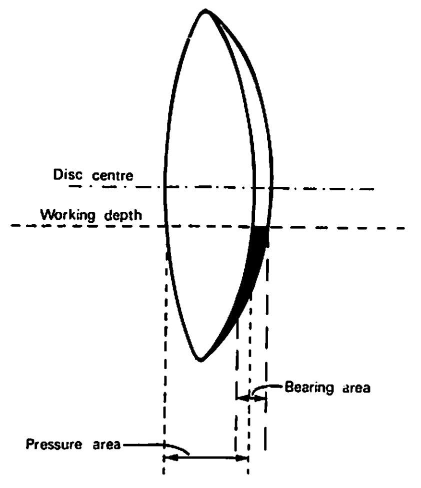


Fig 5 (after McCreery 1958)

Patterson recorded energy inputs roughly equal to chisel ploughing at 180 mm (7 in) depth and half that required for the mouldboard plough at 180 mm depth on the same site. These are net (that is, implement-only figures) and there is likely to be a further advantage where once-over operation allows all the heavy traction to be obtained on firm, undisturbed soil rather than on previously cultivated soil (Southwell & Daynard, 1975).

The figure for power for heavy discs put forward by manufacturers is 20 — 25 kW at the tractor engine/m width of implement. Bowers (1978) puts forward a rule-of-thumb system for matching tractors and implements which puts the engine power requirement at 13 — 22 kW/m. These figures are based on 9 km/hr forward speed. As a practical guide the upper figure in both cases would be appropriate if the implement is to be used for primary cultivation on heavy soils. If there is spare power available forward speed could be increased.

Discs and the soil

The common disc is a section of a hollow sphere, with the dimensions of the disc and soil physical conditions affecting the action of the disc and the forces involved. The disc penetrates and breaks the soil by pressure, with some cutting, pulverising, inversion and lateral movement of the soil. The forward movement of the disc in the soil exerts pressure on it until that pressure exceeds the shear value of the soil, which ruptures in shear planes at about 45° to the vertical. These primary shear planes are formed by the force exerted in the line of travel and occur at a fairly regular interval which depends on the physical condition of the soil. Movement of the soil across the angled and spherical surface of the disc produces acceleration and the formation of secondary shear planes roughly at right angles to the primary planes. It follows that the soil properties affecting the reaction described above — resistance to penetration, compression and shear — are of vital importance in all aspects of disc implement design. This includes weight required, frame strength, disc size and curvature, size of bearings and eventual working speed and draught of the implement.

Penetration by discs is affected by surface trash and soil bulk density more than cohesion or angle of internal friction (Singh *et al* 1978). In any one set of soil conditions penetration is increased most markedly by increase in weight on the disc (McCreery & Nichols 1956) and this is the method in practice available to the operator. Improvements in penetration

Fig 6 Disc Draught Vs Velocity (after Gill 1980)

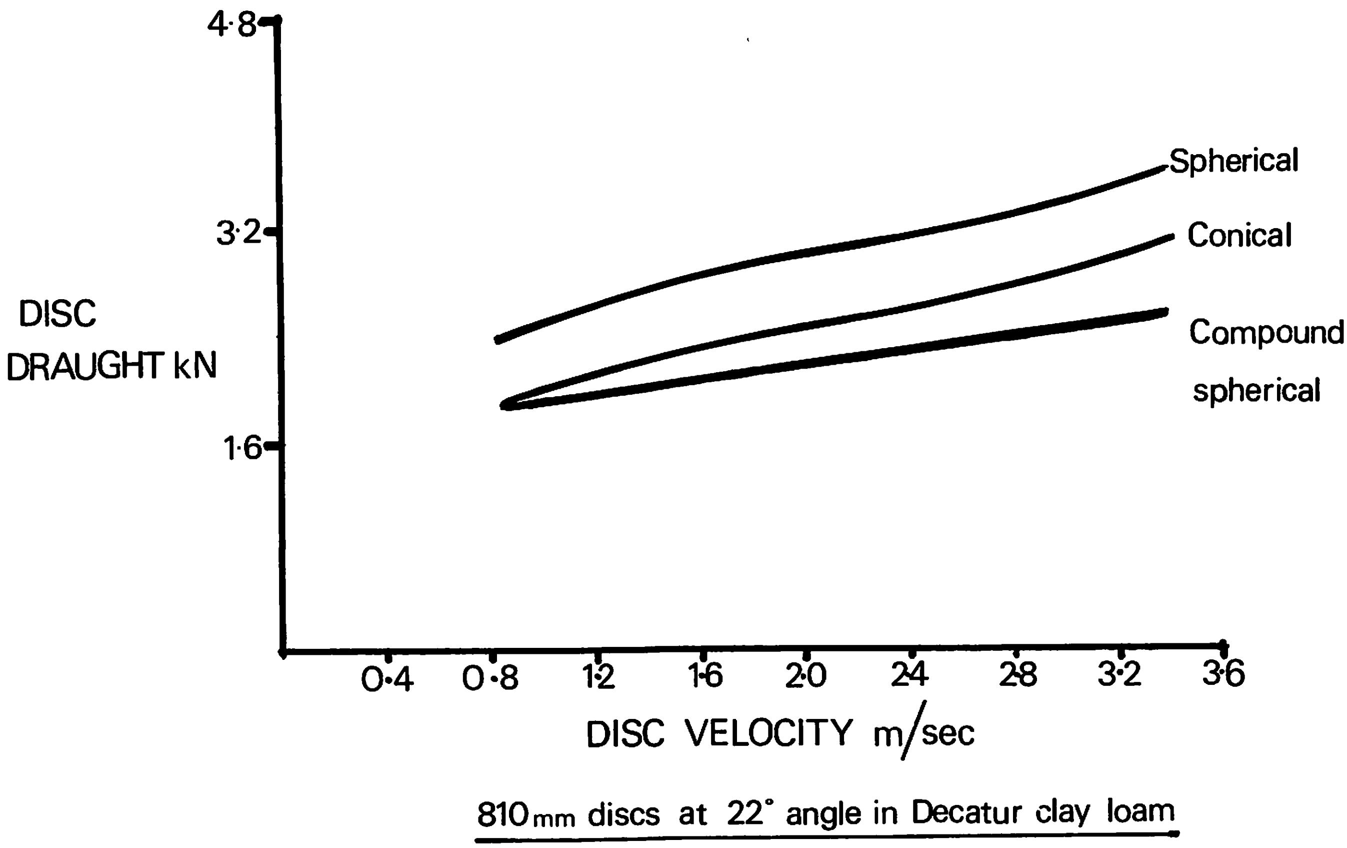


Fig 7 Disc Draugh Vs Disc Angle (after Gill 1980)

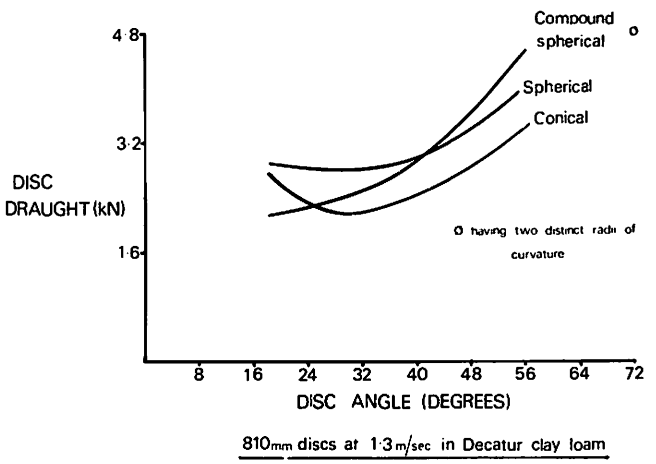
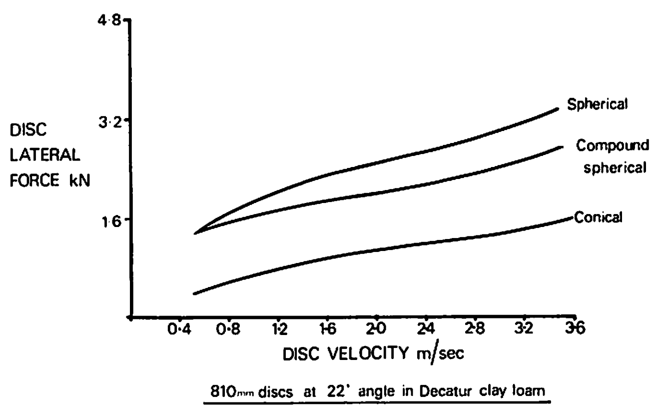


Fig 8 Lateral Disc Forces (after Gill 1980)



also occur with increasing disc angle through the available range of 0 — 30°, as the soil bearing on the back of the disc is reduced and the rotation of the disc is accelerated. (Gordon 1941, Singh 1978). Gordon points out that the better penetration achieved by larger discs in the upright disc-harrow mode is reversed in favour of smaller discs when they are inclined as in a disc plough.

(Gordon 1941) found little difference in the ability of plain and notched discs to penetrate soil when upright even though practical experience suggests that notched discs cut through surface trash more effectively and that the reduced bearing area at the circumference must aid initial soil penetration.

The draught of discs is affected more by soil type and soil condition than any other factor. This is followed by increased depth of working, which causes a rapid increase in draught, and speed, which produces a straight line or slightly accelerated increase. Harrison (1977) reported a small increase in draught with speed, while Gordon (1941) quotes doubling the speed from 4.0 to 8.0 km/hr producing an increase in draught of 67% (fig 6). The draught increase may be partly due to increase in soil strength with rate of loading, but is chiefly due to the acceleration of soil laterally as speed increases. This can to some extent be contained by increasing the radius of curvature of the disc. Those in common use have a radius of curvature smaller than the disc diameter, although Gill *et al* (1980) quote Soviet proposals for discs of 1200 mm diameter with radii of curvature of up to 1800 mm with the aim of reducing soil throw.

Draught is affected by disc angle. The lowest draught angle varies with disc shape and is likely to be in the range 25 — 32° (Gill *et al* 1980), although Gordon (1941) and Harrison (1977) reported minimum draught at 40° and higher (fig 7).

Increased lateral force with increased forward speed and reduced radius of curvature is found, but the important factors are, as with draught increases, differences in working depth, soil type and soil physical condition (fig 8).

Vertical reaction of discs is upwards at low speeds, it declines as speed increases and may be downwards as speed increases further (Gordon 1941). This accounts in part for the improved penetration at speed mentioned by Gordon.

Conclusion

Heavy discs have increased in importance as a primary cultivation implement in Britain. Energy demand is low at about 95 MJ/ha for once-over shallow cultivation for cereals, work rates can be high at up to 80 ha/day with a large tractor and "down time" is extremely low with as much as 1500 ha being cultivated by one implement without major replacement of parts. The forces involved are well known, so that disc implements which produce a level soil finish and a suitable line of draught for the tractor are available. It has been shown experimentally that maximum crop yields can be obtained with this system of cultivation, but there is reason to accept that discs are potentially soil compactors and extreme care needs to be taken in their use.

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Subsoil management

D B Davies

Introduction

"BEFORE I hired a farm I would take with me a labourer and dig a hole in every field to a depth of 2 — 3 ft. That I might know the character of the subsoil, for herein lies the prospect of your success or failure".

The perceptive Mr Mechi, Alderman and farmer of Kelvedon in Essex, wrote this in 1862. Today when potential yields are so much greater and in consequence the water requirement of crops larger, the importance of the subsoil cannot be overstressed even though the proportion of roots it contains is small relative to topsoil.

Regular mouldboard ploughing produces a readily identifiable junction at the base of the plough layer thereby defining the top of the subsoil. However, shallow cultivation and successive direct drilling has already started to blur this distinction. This process will inevitably increase as the newer techniques become more widely established. Although the term 'subsoil' will become less precise this is only of inconvenience to us, because crops respond to the integrated effect of the whole soil profile and not to parts of it in isolation. Management should in consequence be addressed to the total soil profile and should aim to provide continuity of pores throughout it, particularly in the vertical plane. To the engineer this may appear a reasonably simple condition to describe quantitatively and to achieve in practice. Unfortunately, because of the intervention of weather and biological effects there is neither a unique relationship between a physical condition and the response of a crop in the field, nor is it possible to predict with any accuracy the physical soil condition arising from the use of an implement. In consequence, it is unrealistic to believe that soil management decisions will ever be taken at any other than a subjective and/or semi-quantitative level. Nevertheless, within these limitations there is much room for better application of cultivation implements on farms and in this context the present upsurge of farmer interest in how they should be managing their soil is most encouraging.

Response to subsoil loosening

DEEP subsoiling, or moling, to transport drainage water out of fields through pipes and ditches plays a major role in avoiding waterlogging throughout the arable clay lands of England. For convenience this application of subsoiling can be divorced from subsoiling done primarily to loosen the soil which is the subject of the remainder of this paper.

Since the subsoil, as traditionally defined, is in general more compact than the topsoil, loosening has been investigated at numerous sites in the past, and is widely practised by farmers on a range of soils. These investigations coupled with experience of advisers suggest that responses to subsoil loosenings are only likely to accrue where clearly identifiable compaction is present and where fissures and earthworm holes are uncommon within the zone of compaction.

In practice subsoiling is carried out much more widely than can be justified by probable response in the subsequent crop. Availability of adequate power on farms is undoubtedly partly responsible for this situation but equally important is the inability of most farmers to critically examine and interpret physical conditions in subsoil. Their desire to avoid damaging compaction building up in-subsoil is gratifying.

Traditional subsoiling can disrupt only a small proportion of the upper subsoil at one pass and in recent years interest in implements which more thoroughly disrupt the upper subsoil layers has increased. These implements are of 3 main types:—

Winged subsoilers and Paraplow
Tines may be vertical, inclined, or slant-legged. Wings may be attached to increase the zone of shatter. (Spoor and Godwin 1978). Attachments can be fitted to deliver fertiliser below and just behind winged subsoiler tines. Shallow tines preceding subsoiling tines can increase effective working depth.

Oscillating subsoilers (eg Ahrweiler system)
Power from the tractor pto can be used to oscillate tines in a vertical or horizontal plane. The degree and extent of shatter are probably increased and draught is reduced, but power requirement is high and robust tines are necessary. With the Ahrweiler system developed in Germany (Schulte-Karring, 1976, 1979) fertiliser can be distributed in the subsoil during cultivation. The Kaeble Gmeinder vibrating tine subsoiler has been used in several British soils during 1981. This machine has a working depth in excess of 1 m.

Double diggers
The double digger was developed at Wye College (Warboys *et al*, 1979) to reproduce the effects of double digging by hand. A single-furrow plough working at a depth of 0.22 m (9 inches) is followed by a powered subsoiling rotor which cultivates the furrow bottom exposed by the previous pass to a depth of 0.22 — 0.45 m (9 — 18 inches). The rotor has pick tines. Granular fertiliser may be mixed into the subsoil. The forward rotation of the rotor reduces draught, and hence wheelslip. Disruption of the subsoil is more complete than with tined subsoilers, and is possible under a wider range of moisture conditions because of the tearing action of the rotors. The work rate of the single-furrow machine is very low.

Results of subsoil loosening experiments

Wye college
Work at Wye has included development of the Wye double digger. The effects of soil loosening and compaction on soil properties and plant growth were investigated, subsoil fertilisation was tested in more recent trials.

The experiments were conducted mainly on the Wye College Farm ('Brickearth' silt loam, Wood series) with

Table 1 Wye: Effects of double-digging by hand on yields of barley and grass

Crop	*Year*	*Soil*	*Yields* Ploughed control (t/ha)	*Yields* Increase resulting from double digging (%)
Spring barley	1971	Silt	4.14	+14*
Italian ryegrass (first cut low N regime)	1972	Silt	6.77	+88***
	1972	Clay	19.62	-3.5

*, ***: *Significant increase over plough control ($p<0.05$, 0.001 respectively)*

Fisher, Gooderham & Ingram (1975)
El Karouri & Gooderham (1977).

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some work on a swelling clay over calcareous drift, (Wicken series).

Double digging by hand (1971-2: silt and clay)
Hand dug double digging experiments (table 1) were carried out, prior to a mechanism capable of producing this action becoming available.

Root density at the end of the first season was increased by double digging on both soils, but no effect on the distribution of roots with depth was found, in contrast with results of experiments from NVRS. The decline in treatment effects with time was attributed to eventual attainment of the same root density by all treatments. The effects on the clay soil were thought to be related to the generally higher yields on the clay than the silt soil, and hence the smaller potential for increase in yield. It was also found that the mechanical resistance of the clay was less sensitive to changes in bulk density than the silt, under field conditions.

Comparison of subsoil loosening techniques (silt soil)
The effects of the Wye double digger (furrow width 0.45 m [18"], rotor depth 0.32 m or 0.38 m [13 or 15 inches]) and of vibrating and fixed tine subsoilers (spacing 0.70 m [27 inches], depth 0.45 m [18 inches]) on the properties of a silt loam were compared with a ploughed control in 1974-75. The double digger produced a greater increase in water-holding capacity and porosity, and a greater decrease in mechanical resistance than did either of the tine subsoilers; use of the double digger also resulted in the highest yield of sugar beet (table 2) although differences were not significant (Warboys *et al*, 1976).

Table 2 Wye: Effect of subsoil loosening on sugar beet yields

Year	*Yields*			
	Un-subsoiled plough control (t/ha)	*% increase resulting from:-*		
		Fixed time subsoiler	*Vibrating tine subsoiler*	*Wye double digger*
1974	38.3	-4	-2	+ 8
1975	26.2	-1	-4	+11

(No significant differences in yield)

The Wye double digger and deep incorporation of fertiliser (silt soil)
Double digging significantly increased yields of winter wheat and spring barley on a silt soil in 1978 (Warboys *et al*, 1979). The simultaneous incorporation into the subsoil of low rates of P and K (38 and 73 kg/ha respectively) had no additional effect on yields (table 3).

Table 3 Wye: effects of double digging and deep incorporation of P and K on cereal yields.

Crop	*Yields (grain, 85% DM)*		
	Plough control (t/ha)	*% increase resulting from*	
		Wye double digger alone	*Wye double digger + Deep P K (38:73 kg/ha P:K)*
Winter wheat	3.86	+15*	+10*
Spring barley	4.08	+ 7*	+ 3

**Significant increase over ploughed control ($p<0.05$)*

National Vegetable Research Station

The effects of subsoil loosening have been approached from both practical and theoretical angles at NVRS. Models of water use as a function of root development have been used in an attempt to explain the effects of loosening and fertilising subsoil. The vegetable crops which were used in this work are beyond the scope of this paper, but the results are recorded elsewhere (Rowse *et al* 1977, 1978a, 1978b, 1980, 1981, Stone 1977, 1978).

Rothamsted experimental Station

The effects of loosening and fertilising the subsoil have been investigated using a variety of techniques at Rothamsted, Brooms Barn and Woburn.

Brooms Barn: (sandy loam, Moulton series)
The subsoil in some areas of Brooms Barn was considered to be indurated, of poor structure and relatively infertile. Conventional subsoiling had become routine but a field which had not previously been subsoiled was cultivated with the Wye double digger in autumn 1975. Fertiliser (P and K,55:105 kg/ha) was either incorporated into the subsoil, or was broadcast on the seedbed in March.

Sugar beet showed no response to either subsoil loosening or deep incorporation of fertiliser, all yields being depressed by drought. Differences in bulk density of the subsoil immediately after double digging or ploughing (1.34 and 1.45 g/cm^3 respectively) were no longer detectable in May or October 1976, so the duration of effects of cultivation on the subsoil is uncertain (Jaggard and Webb, 1976).

Woburn: (sandy loam, Cottenham series)
A long-term experiment at Woburn (1973/9) involved double digging by hand to 0.46 m (18 inches) in 1973, with incorporation of heavy dressings of P and K into the subsoil of some plots. The rates applied (843:382 kg/ha P:K) were intended to raise available P and K levels in the subsoil to those in the topsoil. Control plots were undisturbed, with or without the same heavy dressings of P and K applied to the topsoil. All plots were ploughed annually to 0.25 m (9 inches) and given surface fertiliser appropriate to the following crop. A four-course rotation (wheat, barley, potatoes and sugar beet) was grown in each of the following four years. Barley was grown on all plots in the fifth and sixth years. This experiment continues, to see how long the effects of the 1973 treatment will persist. Mean effects on yield are shown in table 4. All crops except potatoes benefited from subsoil

Table 4 Rothamsted: Effects of double digging and heavy fertilising of the subsoil on yields at Woburn

Year	Crop	*Yields*			
		Un-subsoiled ploughed control (t/ha)	*% Increase due to:-*		
			Double digging alone	*Double digging plus 843:382 kg/ha P:K in subsoil*	*843:382 kg/ha P:K in topsoil*
1974-7	Wheat	4.3	+20***	+18***	-6
	Barley	3.4	+26**	+46***	0
	Potatoes	45.4	0	+16***	+7
	Sugar beet (sugar)	4.6	+10**	+14***	+2
1978	Barley	5.3	+ 7	+19***	+6
1979	Barley (a)	3.9	+12	+12	0

*Notes *, **, ***: significantly different from ploughed control ($p<0.05$, 0.01, 0.001 respectively).*

(a) statistical analysis not available.

loosening, even though no plough pan had been detected before treatment. All crops except wheat benefited additionally from deep incorporation of fertiliser.

Rothamsted and Woburn: (silty clay and sandy loams)
Standard subsoilers, the Wye double digger and ploughing alone in the autumn were used at Rothamsted and Woburn in a comparison of subsoil loosening and fertilising techniques (1977 — 79). High rates of fertiliser (843:382 kg/ha P:K) were incorporated into the subsoil during the double digger treatment.

Spring barley was followed by field beans. Yields after double digging were consistently higher than after tined subsoiling or ploughing alone. The deep incorporation of P and K further increased yield in most cases (table 5).

Results suggested that thorough disturbance of the subsoil was required for yield benefit on both the sandy and clay soils, and that the Wye double digger achieved similar effects to subsoiling by hand. (McEwan *et al*, 1978; McEwan and Johnston 1979). This experiment continues.

West Germany

The Ahrweiler soil amelioration system has been developed in West Germany to overcome compaction and drainage problems in the subsoil by creating an open structure (Schulte — Karring 1976, 1979).

Oscillating subsoiler tines were found to give more intensive and extensive shatter than rigid tines, and to displace soil particles more, so that settling was reduced. Three types of oscillating-tine subsoilers were developed, varying in the proportion of power used to vibrate the tines, in geometry and in working depth, enabling a wide range of soil types and conditions to be treated. Fertiliser could be blown into the subsoil during treatment, and it is considered that stabilisation of the new subsoil structure was enhanced by the fertiliser.

The Ahrweiler system comprises subsoil loosening and fertilisation in the autumn followed by seedbed preparation, and sowing before the next rain. Grass or root-intensive crops are preferred in the first years. The tillage of wet soil, and therefore spring crops, should be avoided. These measures are all designed to allow stabilisation of the new subsoil structure.

In long-term trials on surface-water gley clay soil with a compacted subsoil, yield increases as a result of subsoil loosening and fertilisation persisted for 15 years and averaged 18%, the benefits being greatest in wet years. The benefit was thus due to improved drainage, as with much conventional subsoiling, and in contrast to most UK trials considered in this paper. The effects of loosening on air-filled porosity also persisted at depth, but a new plough pan developed.

ADAS loosening experiments

Subsoil loosening
Impressed by the series of trial results at Wye, Rothamsted and NVRS, ADAS in 1980 started a series of experiments to assess responses to more complete subsoil loosening on a wider range of sites. The Wye double digger and an NCAE winged subsoiler, with and without subsoil fertiliser placement, are the basic treatments in these trials, four of which have started, with more planned to start in 1981 and in subsequent years. The only results available at the time of writing, are from an experiment in Kent where no responses were obtained in the first year. Despite a strongly compacted subsoil pan at this site, earthworm channels, allowing roots and water to penetrate, are reported to be a feature which may be responsible for the lack of response.

Loosening of direct drilled land
In a further series of experiments in Eastern Region of ADAS the Howard Paraplow has been used to loosen compact soil in 7 experiments where plots have been direct drilled for several consecutive years and compaction has arisen. These experiments are conducted jointly with Plant Protection Ltd and are designed to test the effect of implements which loosen but leave the surface comparatively intact and free of large clods. Responses varying from nil to 0.7 t/ha of grain have been recorded in the first year.

Table 5 Rothamsted: Effects of deep loosening and heavy fertilising of the subsoil on yields.

Year and crop	*Site*	*Yields*			
		Un-subsoiled ploughed control (t/ha)	*% Increase due to:-*		
			Standard tine subsoiler	*Wye double digger*	
				No P, K in sub-soil	*843:382 kg/ha P:K in sub-soil*
Barley 1978	Rothamsted	4.4	+ 5	+18	+36***
	Woburn	4.3	+14	+23	+28*
Beans 1979	Rothamsted (a)	3.6	0	+ 6	+14
	Woburn	1.4	-14	+ 7	+36

*Notes *, ***: significantly different from ploughed control (p <0.05, 0.001 respectively).*
(a) statistical analysis not available.

Summary of recent subsoil loosening and fertilising experiments

Considerable increases in yield of a variety of crops have been achieved in recent years after deep loosening of soils, and also after deep incorporation of fertiliser. Work in the UK includes trials by workers at Wye College, Rothamsted Experimental Station and the National Vegetable Research Station.

The benefits of subsoil loosening appear to be related to the degree of disturbance achieved, since use of the Wye double digger at Wye, Rothamsted and Woburn (silty, silty clay and sandy soils) gave consistently positive effects on yield in trials where tined subsoiling gave smaller or negative responses. Double digging by hand, and soil excavation (in the NVRS pit experiments) have also given significant yield benefits for several crops.

The longevity of beneficial effects is considered to be related to the degree of subsoil loosening initially achieved, soil moisture content at the time of cultivation, soil type, and subsequent traffic and cropping. It has also been suggested in West Germany and the USA that subsoil fertilisation, by promoting rooting and other biological activity, might stabilise the loosened structure. The effects of double digging at Woburn (sandy soil) have lasted seven years to date, while the effects of vibrating tine subsoiling with deep fertiliser in West Germany (clay soil) have lasted over 15 years. In some trials where plots were ploughed annually, a compaction zone developed rapidly with looser soil below.

The porosity and water-holding capacity of the subsoil were invariably increased by deep loosening, and the mechanical resistance decreased, providing a more favourable rooting environment. Where measured, the rate of root penetration to depth, water uptake at depth and total nutrient uptake increased together with yield. Total water uptake was not necessarily affected. These effects were found both in the presence and absence of fertiliser incorporated into the subsoil. The conditions under which responses to subsoil loosening are expected have not been clearly established. Interpretation of results is complicated by soil and climatic differences, and by the fact that the detailed assessment of effects of treatment on soil physical properties and plant growth are not always available. In the UK (and in North America) yield benefits have often been attributed to increased water use by the plant — whether due to increased water supply or greater rooting at depth. Workers at NVRS have suggested that greatest benefits might be expected in years of moderate (rather than extreme) water stress. On the other hand subsoil loosening on clay land with impeded drainage in West Germany resulted in greatest benefits in wet years. The degree of compaction which may limit yield is also uncertain. In some trials, responses were observed even though subsoil compaction was not considered severe.

Incorporation of very high rates of P and K into the subsoil at Woburn (sandy soil) increased yields of arable crops over and above the effects of double digging alone. The effects have persisted for seven years. However, where subsoil fertiliser has been applied at rates similar to surface dressings, responses have been smaller or absent. No information is available from UK trials on the effects of fertiliser on subsoil structural stability.

Conclusions

Due largely to the work of Spoor & Godwin we now have a better understanding of how to achieve soil loosening more effectively. Inevitably subsoil loosening has a very large power requirement and is a time consuming operation. Consequently it is important that we and farmers should be able to identify readily, conditions where loosening is likely to be financially beneficial. Prior to the present generation of subsoiling machinery, ADAS advisers were confident that they could identify such conditions with reasonable accuracy. With implements capable of loosening subsoil thoroughly the Wye College and Rothamsted work suggests we may have to modify our criteria for subsoiling need. The present series of UK experiments should provide the evidence on which to decide what, if any, modification is needed.

If it is decided that more intensive loosening of subsoil will be widely beneficial, engineers will need to develop commercial implements for this purpose. To this end it is important to establish conclusively the comparative performance of loosening with fixed compared with powered vibrating tines. We may predict that on clay soils rotary tines will be less effective and vice versa on sandy soils but this remains conjecture at present.

Predicting the benefits of fertiliser placement in the subsoil is not possible at this stage. Responses, additional to those from loosening alone, have been few in number and inconsistent, except at Rothamsted where very large amounts of fertiliser were mixed with the subsoil. Until the mechanism of these responses is better understood and results from a wider selection of soils and crops are available, it will not be possible to provide reliable advice on the worthwhileness of the practice.

Loosened land is very susceptible to over-compaction and the full benefits of subsoil loosening will not be achieved until agronomists, engineers, and machinery manufacturers turn their attention seriously to reducing wheel loadings throughout arable farming Apart from low ground pressure vehicles which have probably been developed to allow access to land at times when conventional machines could not function rather than to reduce soil damage, there is little indication that machinery manufacturers consider this aim important. The need to reduce wheel loadings is even more urgent for reduced cultivation and direct drilling systems and it is unlikely that underloosening implements such as Flat Lift and Paraplow would have been needed if manufacturers had appreciated this problem and found solutions. The real opportunity of substantially reducing machinery costs on the majority of mainly cereal farms is being frittered away because so little constructive effort has been applied in the UK to finding acceptable methods of reducing compaction from wheels.

Finally we must return to the question of identifying conditions where soil loosening will be beneficial. Although trials provide us with an invaluable backbone of information on crop response to a range of soil conditions, application of this knowledge onto farms can only be through soil examination, perhaps backed up by simple physical measurements. Most farmers are not trained or practised in soil examination and until the agricultural education establishments accept the training of agriculture students in this skill as one of their prime responsibilities, little improvement can be expected. We are left with the unpleasant conclusion that the current development work designed to improve return from subsoiling and soil loosening in general is likely to give poorer returns in commercial practice than it could, were it to be more professionally applied.

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Practising the principles

R G Dawson

THE Law of the Limiting Factor states that at any one time crop yield is limited by one factor only. The Law may be analogised by a barrel with staves of uneven height, the crop yield being represented by the amount of water in the barrel which is limited by the height of the shortest stave, the limiting factor. Yields can be increased by altering the shortest stave but no increase of any other stave will affect yield at all, unless and until the shortest stave has been increased sufficiently to make some other stave limiting in its turn.

If trials are testing the limiting factor (the shortest stave) then they will produce yield responses up to the level limited by the next limiting factor, and hence possibly significant results. However if the experiment is altering some currently non-limiting factor then there will be no significant response but, and this is the crucial point, this lack of response would not justify a claim that there would also have been no response at higher levels of yield, such as would have been obtained if the earlier limiting factors had been removed first.

Therefore in low yielding trials a result of "no significant difference" can tell us nothing of the possible responses at high yields. Ideally trials should work with no limiting factors save that under test; and we may recognise such trials as those with yields near the maximum potential of the site or with yields large by the standards of the potential users of the trial results.

Thus most of the cultivations trials yields at Rothamsted presented by Mr Patterson were around five tons per hectare; whereas we know from the multi-disciplinary wheat trials at Rothamsted in 1980 and 1981 that the site potential is well over ten tons per hectare. Therefore I do not believe that his rather negative result of not much differnce in yield between cultivation systems would necessarily apply at higher yield levels, although clearly the positive result that direct drilling sometimes depressed yields meant that limiting factors were involved.

I believe that once the fascinating subsoil loosening trials described by Dr Davies are carried out at high yield levels, then we will find yield benefit from subsoil loosening; though economic benefit is less sure, and would demand machines with much greater capacities than are presently available.

Dr Davies said in conclusion that "loosened land is very susceptible to over-compaction" and this grave danger coupled with the lack of demonstrable economic benefit means that I will not loosen the subsoil routinely. However most of the speakers emphasized that water must be able to infiltrate readily and that roots must be able to penetrate deeply, and if either of these conditions is not met then subsoiling is necessary.

It has been suggested (Davies 1975) that a good crop, especially in a dry year, shows that the roots must have penetrated deeply, and hence there cannot be a serious pan, at least within the reach of cultivating equipment.

Accordingly we have monitored our individual field yields for the past six years. We weigh using the "Weylode" approach of measuring hydraulic pressure in the tipping ram pipe of a trailer tipped 10 cm from its bed. If a haulage distance of a kilometre or more is involved the grain seems to level itself satisfactorily but with shorter hauls the combine driver takes care to spread the load evenly. We calibrate empty and full and then calculate the weight of grain in each load, which we also correct to 15% moisture. For each of the last three years out total yield estimated in this manner has been within 1½% of the total weight of grain sold.

I look for fields whose yields are declining in relation to our average yields. In practice we have detected no need for subsoiling in the last five years of direct drilling; but we have found the gradual development of a "platiness" at 3-4 cm has shown in declining relative yields. Yields seem to drop by about 10% in the first year of the condition, by a further 10% in the second year while the third year can be a disaster.

This year we turned to mini-tilthing to try and mitigate the condition. We used a Tasker Tillage Train which, apart from being expensive to run (tine point wear alone cost £3.50/ha) did not fully cure the problem. Mr Finney's paper explained why; the tines go first and run just below the level of the discs; however the discs then reconsolidate this layer which was 4 — 5 centimetres deep, and so included some of the very layer we were trying to loosen.

Mr Spoor presented five desirable targets for cultivation systems; root penetration and water infiltration have been discussed; trafficability is best with the least cultivations; trash control I will come to later, so let us consider tilth.

Mr Hubbard regards good establishment as being "essential for a reasonable insurance" but also thinks that the "compensatory growth" characteristics of wheat should make up for any deficiencies in establishment. Dr Traulsen expressed an opposite view as his agronomists demand excellent seed beds to enable todays more sophisticated drills to establish precise populations, evenly spaced and with depth control to within 15 mm. Dr Traulsen's trials show this sort of precision is worth an extra five to ten per cent in yield or, in other words, that relying on compensation is not enough.

To decide between the two approaches we must think about "compensation". There can be no doubt that it exists, the question is whether a crop that has needed to compensate for some deficiency will yield as much as a crop that has not had to compensate.

Mr Spoor mentioned compensation; a waterlogged crop, with populations as low as 12 or 38% of the control did compensate, and the yield came up to 82% of the control. Clearly there was some compensation, but the control that did not need to compensate yielded 18% more.

I only know of one investigation that attempted to measure compensation. (Doughty and Engledow 1928). In the Autumn 200 lengths of row, each one foot long, were marked out and the established plants in each counted. Each length was harvested separately and the yield compared with the Autumn plant count in a quintile analysis, shown in table 1.

Beyond doubt some compensation was involved, each individual plant in the low density strips yielded about 16% more than each individual plant in the high density strips; but this was nothing like enough to compensate fully for the low density. For compensation to be complete then the yield from each foot would have to be the same, irrespective of how many plants were in that foot. This was not so and therefore full compensation did not occur.

As the yield of each strip was proportional to the number of plants in that strip I think the trial shows clearly

Table 1

Plants in 305 mm	*Mean plants*	*Yield per plant gm*	*Yield per 305 mm gm*	*Equivalent plants sq m*	*Equivalent yield t/ha*
1 — 8	5.9	3.04	18.2	96	2.9
9 — 10	9.4	2.44	23.1	152	3.7
11 — 12	11.4	2.26	26.0	184	4.2
13 — 16	14.6	2.16	31.7	235	5.1
17 — 24	18.7	1.51	28.4	300	4.6

A quintile analysis of plant population and yield from 1 foot (305 mm) lengths of drill rows of winter wheat. After Engledow (1928).

the importance of accurate even establishment, and so, while I am glad to accept the help of compensation when I get things wrong I believe, with Dr Traulsen, that precise establishment is vital for optimum yield and requires an excellent seed bed.

Mr Spoor's last main consideration was for trash control, which is straightforward. If the trash is not removed then it must either be burnt (if possible and legal) or buried. If straw has been burnt then the ash should be dispersed for optimum herbicide effectiveness and, of great importance, the early dispersion of ash removes one of the main causes of nuisance to the public. We find a pressure harrow copes easily with 80 ha/day, and if it starts almost before the fire has gone out it can leave a really lovely tilth into which to drill.

Weed control by cultivation has decreased in importance. Perennial weeds are hardly a problem now pre-harvest glyphosate spraying is available, and spot treating at that time is so easy that perennial elimination is both possible and economic. Blackgrass is the most costly weed and both buring and ploughing help to contain it but Naylor (1972) showed that even the best mouldboard ploughing failed to bury quite all of the blackgrass seed, leaving enough for the infestation to continue and so I fear we must continue to rely on chemicals.

For wild oats and the broad leaved weeds there is not much evidence that one cultivation system is superior to any other, and what evidence there is is sometimes contradictory. The same may also be said of disease control and, except for slugs and surface straw, of pest control.

I have met a problem with acidity and direct drilling. Conventional analysis of the top 150 mm of the soil has produced satisfactory pH of 6.5 or 7, but analysis of each 25 mm of the profile has shown the top layer or two to be acid (pH 5 — 6). I hope we can solve this by more frequent, albeit smaller, applications of chalk, although inversion would also cure it.

To summarise so far I think Mr Spoor's four main objectives can be met without ploughing, but we may want to plough for nutritional reasons or to control sterile brome grass while if we can not burn the straw we will have to plough.

My brief today was to talk on "principles into practise" and so now I want to see how we might use the information given us today to devise a cultivation system that could cope with unburnt straw.

We would start with straw chopped by the combine, and spread as evenly as possible. We want the straw to decompose quickly and throughly, and can use the principles of composting to guide us. The higher the temperature the better, and so the rotting needs to start as soon after combining as possible. The operation will be better if the straw is well mixed with the soil and if as much moisture is conserved as is possible.

The micro-organisms will also draw available nitrogen from the soil, up to perhaps 8 kg per ton of straw, and this will be unavailable to the plant for some time, though work at Letcombe (Lynch 1979) has shown it will be released later. Accordingly to avoid nitrogen deficiency in the crop we will have to apply nitrogen, and as it is needed to break down the straw let us spray it onto the straw before incorporation. As the nitrogen will be available later the only extra cost is the investment cost of the earlier application.

We cannot plough the loose straw directly as the plough would block up; so we mix the straw into the top few centimetres, using discs. We need good covering, freedom from choking and, pre-eminently, good penetration with depth control being less important. Using Mr Finney's paper we see we buy a heavy machine with large diameter discs, which due to the importance of penetration should be quite widely spaced even though this is at the expense of covering, and we take the conventional compromise between penetration, by having scalloped front discs, and covering by having plain rear discs. In the field we set the angle as steep as we can without choking, and then go as fast as possible. With wide, winged, discs if we meet a hard area we lift the wings, thus increasing weight on the middle discs.

The ploughing we want is not that of the conventional set up slice; we are ploughing to break the soil up, to get the straw away from the seed germination zone and to mix the straw and soil intimately together. All of these objectives are best met if we go fast, at least 9-10 km/h, but this would not be possible on hard August stubbles. However if we cultivate once or twice with heavy spring tines (eg Vibroflex) then this will allow fast ploughing, it will aos break up any compaction caused by the discs and it will solve any residual Problems from the previous year's ploughing, provided the tines run just below the level of that ploughing.

As Mr Spoor told us, we should keep the ploughing tractor wheels on the surface rather than in the furrow, and although he would not approve of our working on loose soil at least we are re-arranging it afterwards. We want to conserve moisture and so we level and firm directly behind the plough, possibly with a press. I envisage all of these operations as being carried out close behind the combine, preferably in hours rather than days. Drilling might be possible with no further operations, though if necessary a cultivator could be used in combination with the drill.

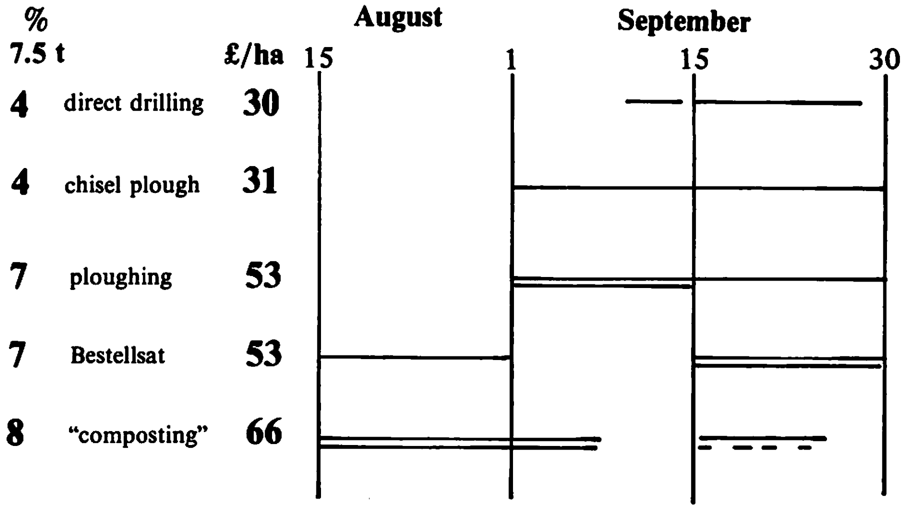
This system, which is akin to one used with great success in parts of France, would provide the excellent seedbeds asked for by Dr Traulsen as well as providing a technical solution to the problem of straw trash. However we do not farm for technical solutions, so let us think of economics.

We have heard much talk of comparative power and energy requirements, but the costs of the most expensive system discussed by Mr Patterson, the Boxworth plough-cultivate-drill system can be broken down into elements of labour (12%), repairs (28%) and ownership costs, interest and depreciation (49%) with fuel (11%) being the lowest part of the costs. The ownership costs are largely determined by the relationship between the area the system is to cover (in my case 300 ha) and the time it is to be allowed to operate in.

Mr Hubbard gave the optimum drilling dates as being from 20 September to 20 October, and thought the penalties for being outside this range would not be very great. I think this too lenient, for example at Letcombe (Ellis and Lynch 1976) there was an 11% reduction in yield from drilling on 17 October as opposed to 3 October for the extremely dry harvest of 1976; and I think autumn 1981 will have shown many people the attraction of finishing drilling in September. This then is my target, to finish in September, and to do so I will start on about 15 September, or if I grew barley on 10 September.

For the system capacities and costings I have used Mr Patterson's methods (as detailed Patterson *et al* 1980), but I have taken earlier drilling dates, and hence a shorter season. I have assumed my own land area (300 ha) and have also assumed interest at 15% and the use of larger tractors (100 kW rather than 56 kW). As I have followed Mr Patterson's methods there is no allowance in time or money for the preparation of fire breaks, although on my farm this occupies one skilled man

Fig. 1 Illustration of timings of five cultivation and drilling systems discussed at the conference. Each horizontal line represents the period in which some operation is carried out by one man. Costs are shown both as £/ha and as a percentage of the value of a wheat crop yielding 7.5 t/ha at 1981 prices.



virtually throughout the combining period.

Figure 1 illustrates the seasonal timings and the costs for three systems discussed by Mr Patterson, direct drilling, chisel ploughing and full ploughing, for the Bestellsaat system discussed by Dr Traulsen and for the composting system I have just proposed.

In practice not much straw is burnt before the end of combining and I have assumed that in the straw-burning systems cultivations cannot start until 1 September, whereas if the straw is to be incorporated then cultivations should start as soon as the first land is clear, perhaps 15 August. Consequently, the chisel plough and ploughing systems are under pressure to complete all their work in 15 days, with no allowance for weather conditions whereas the Bestellsaat and composting systems both have time in hand in early September. The Bestellsaat system suffers from drilling being limited to the rate of ploughing, while the composting system requires two men to be cultivating while the combines are operating, which is inconvenient. However, in my case the skilled man who used to be making the fire breaks could drive the ploughing tractor while the discing and cultivating could be done by a student. The straw incorporation systems gain their time advantages partly by not waiting for straw to be burnt, and partly by the high speed ploughing which is possible when the soil has first been loosened by a cultivator.

Direct drilling is still the cheapest system, and one third of the cost shown is for sprays which are costed for the whole area although, in my experience, this is not always essential, especially when the same cereal is being grown for the second year running. The Bestellsaat system is much better than the conventional ploughing and costs the same; while the extra £13/ha for the composting system is less than I used to think a ban on straw burning would cost. In fig 1 the system cost are also shown as a percentage of the value of a 7½ t/ha crop. The difference in cost between the cheapest (direct drilling) and dearest (composting) systems is only 4% of the value of the crop, a figure comfortably covered by Dr Traulsen's claims of an extra five to ten per cent yield when excellent seed beds are provided, which seed beds I believe the incorporation systems can provide and which I do not believe direct drilling can be relied on to provide on a regular basis.

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Soil management for cereal production

Questions following paper 1 (Mr K R Hubbard)

1 Mr R S Norris (farmer, Essex) I was horrified by Mr Hubbard's French trench in which the tramlining effect went down to a great depth. Are you suggesting that if we are tramlining we should try to keep the tramlines in the same place each year because of our inability to repair the damage caused by them?

The illustration was of an extreme case. The soil in question was a fine sandy loam and I don't expect that we would see the same sort of problem on most of the chalky boulder clays which we have in this country.

2 Mr Stokes (Ransomes, Sims & Jefferies Ltd) I was very interested in your slide showing root penetration and the fact that the number of roots decreased with depth. Is it possible to estimate how much water is taken from the progressive depths as they go down as it seems that the cost of cultivating deeper and deeper goes up almost exponentially and there must be a break even point?

What we are talking about is having soils of the right sort of structure at depth naturally, or by good drainage, which will allow good root penetration. Nobody is envisaging that one needs to cultivate to that sort of depth.

3 Dr C P Johnson (farmer, Essex) Can Mr Hubbard elaborate on his contradiction of trying to get roots to go right down when he also said that a lot of cultivations, especially deep ones, were really redundant. Which cultivations, in his opinion, are the ones which allow the roots to get as far down as possible?

Cultivators and subsoilers should be used to get rid of pans if by examination it has been established that problems exist. Subsoiling is not a good thing just because you have a great big piece of equipment in the yard which will do it. Fortunately in your soil you have got good structure down to depth and you can get your roots down to that level. Hence even in a good summer you get reasonably good wheat yields, albeit that they would be increased by a reasonable precipitation in June and July. There are other interacting factors involved as well. If you have high temperatures you will tend to have difficulty with water supply and you will get earlier dying back with high temperatures as we experienced in 1976.

4 Mr D J Hodge (farmer, Herts) Shorter strawed cereal varieties seem to be suffering more in terms of drought. Is there any relationship between above ground dry matter and below ground dry matter?

I don't really think that you are right in believing that the shorter strawed varieties will yield less than the longer strawed ones in what one might call a "droughty" situation. There is some controversy over this, but the variety trial results tend to show that, for example Hustler and Huntsman have the same sort of relationship, albeit at a lower level of yield, under dry soil conditions as they do under better conditions. So I don't really think there is a question to answer on this and your experiences, which are probably based on a field by field comparison, should perhaps not cause you to reach this conclusion. Studies on roots are inordinately difficult to do because one has to get the roots up in order to assess the situation. I don't know of any particular studies which have been done to compare dry matter above and below ground.

5 Mr J S Rymer (Chairman) I would like Ken Hubbard to comment as an agronomist on how far he feels we have got in terms of the potential of the cereal crop, how does 10 tonne/ha relate to the ultimate crop potential with our climatic limitations of water availability and radiation? One hears of the possible potential in some other crops, for example sugar beet, where 100 tonne/ha is supposed to be technically within our grasp. I am asking this question because what we are talking about during the course of today is really fine tuning all the way down in the ground to try and get ever nearer to the optimum yield.

Thresholds will be increasing as we go on, plant physiologists would say 13 tonne/ha is achievable. I personally have measured more than this in part of a field but it needs a fortunate combination of circumstances.

Questions following paper 2 (Mr G Spoor)

1 Mr R G Martin (farmer, Romford) Do the criteria that you put forward with regard to compaction as far as wheeled tractors are concerned also apply to track laying vehicles?

The same criteria apply but the advantage is that ground pressures are lower, providing tracks are adjusted sensibly and correctly. If you have got badly adjusted tracks then the pressure under the rollers can be very high indeed.

2 Mr J Turvey (farmer, Northampton) Should we use hard face welding rods on the underside of points of shares to remove the damaging angle on the leading face?

As long as you can keep an acute angle, acute in the direction of travel, so that the soil is tending to be lifted upwards, you are going to minimise the compaction effect. So if you can build up your shares so that you keep this very sharp angle then this is what is required. You are bound to get some smearing at the interface what ever you do. But it is when the shares angle turns over and you get a parabolic shape on the front end that the bottom starts to push down and we start to get serious pan problems.

3 Mr R R Gladden (Adviser, Norfolk) Is any work being done on the use of seed press wheels under dry conditions in this country for crops other than sugar beet? Mr Hubbard mentioned the dangers of a dry seedbed and I do know that in countries with dry climates a lot of work has been done on drills which have a device for pushing the seed into the bottom of the furrow before covering it, as opposed to effecting overall coverage afterwards.

Mr J C Ives (West Suffolk from the floor) *I use successfully a minimat drill in conjunction with a subsoiler used at right angles to the direction of drilling. The drill, in effect squeezes the seed into the soil. The drill is carried on a furrow press so after drilling no wheelings can be seen.*

4 Mr N Warshaw (farmer, Essex) You suggested that after superficial or deep soil loosening one could cause a great deal of damage by going on the land with wheels afterwards. Did you mean immediately afterwards or at any time afterwards, even a year later?

If we are loosening soil when it is moist it is in a very vulnerable condition and it can be compacted by wheels so that it ends up in a far worse condition than it was before it was loosened. When we loosen soil, we break many of the bonds which stabilise the aggregates and the clods and it takes time for these to reform. If we can wait before subjecting the soil to further wheeling it gives some of these bonds time to reform so that the soil is less vulnerable. Therefore if we can wait there is less risk. But if you have got very loose conditions then very low pressures indeed will cause damage.

5 Dr D B Davies (ADAS, Cambridge) I agreed with virtually everthing which Gordon Spoor said this moring but I am a bit concerned about his comments regarding fine seedbeds holding up water if the porosity is too low in the upper layers, with the coarser porosity below. I would expect that in most instances the advantages of fine seedbeds for early sowing of winter crops would outweigh any small disadvantages of the type that he described. Personally I have not seen the condition which he was referring to of a fine porous top, overlying a coarser material below, so that rainwater does not flow across the junction. Perhaps he could tell us whether he has seen this in practice under British field conditions?

We have seen this in situations in cracking clays where there are large shrinkage cracks present, where people have scratched the top and produced a consolidated fine seedbed which will hold quite a lot of water. Similarly, if we look at soil moisture status in direct drilling situations we can find higher moisture content in the upper layers. The reason I am raising it is that there have been a number of farmers commenting on this very wet top and the important thing to clarify is whether the problem is in the top or not. Very often if people see wet tops they suspect compaction problems at *greater depth and they then go through next season to remedy them when in fact the trouble might have been relatively shallow. So yes, we certainly have seen it and all I would suggest is lets try to keep our tilths as coarse as we possibly can rather than follow the current trend to finer and finer seedbeds because finer must be better.*

6 **Mr G F D Wakeham** (Harper Adams College) Mr Spoor has implied that all tillage equipment produces a smear. If he is saying that subsoilers smear, how long will it be before we have to subsoil our subsoiling?

If we are using tools when the soil is moist and clods are weak then there is going to be the likelihood of smear. This is why with any tining technique we have got to minimise the number of operations. The implement does not have the final effect fortunately for us. If in fact we can improve conditions by using tools at particular depths to encourage better and more vigorous root development, more vigorous organism activity and more wetting than drying, then the chances are that the little bit of damage that has resulted underneath that tool will be quickly rectified and we will not get a problem.

7 **Mr B A Linger** (Howard Rotavator Co Ltd) I have been very interested to hear Mr Spoor's comments with regard to wheels and soil structure. I wonder whether he would like to comment, in the light of the need for good soil strength for tractor wheeling, on the feasibility of soil loosening after drilling?

The difficulty with soil loosening after drilling is that we have got to match tractors to the draught requirement of the implement which is being used so that wheel slip and wheel damage are minimised. If this can be achieved the results could be better than preparing the seedbed and then drilling when the wheels of the tractor and the drill itself pass over the seedbed. In many cases we have got to go through the crop later, possibly with tramlines. Why do we have the ridiculous situation which we have got with drills at the moment where the wheels are located at the extremity of the drill? Why can't they come in behind the tractor wheels and run in the same track? There are many things that we can do and there are many things that you can do as farmers in your own workshops if you really get this wheel bit between your teeth. What I suggest is that we should forget about all these wonderful cultivation implements which we are going to talk about for the rest of the day and just concentrate on wheels, because they are having the biggest effect. There is no doubt about it and the sooner we realise it and do something about it, the more profitable your enterprises are going to be.

8 **Mr J W Roberts** (farmer, West Suffolk) What guidelines can Mr Spoor give us for establishing seedbeds for a wheat crop behind sugar beet in November/December?

If you have been harvesting beet in a very wet back end, you have problems. These can be minimised by using multi-row tanker harvesters. As far as cultivations are concerned, providing you work from the surface downwards, you can achieve loosening and take compacted zones out under very wet conditions. If you go in deep and try and heave the whole thing up from the roots then you will be in real trouble. You have to accept that things are not going to be ideal — you have got damage there and so do the best you can to alleviate the problem as far as you can in the autumn with the intention of doing more after harvest the following year to rectify the trouble, hopefully under better conditions. I don't want to specify implements at all but there are many occasions when we could optimise the use of the plough by attaching loosening tines to the bodies.

So my approach would be to minimise the wheelings as much as you can during sugar beet harvesting and treat them as local. Do what you can do with the plough because it is the master in that situation.

Questions following paper 3 (Mr D E Patterson)

1 **Mr R White** (farmer, Suffolk) You made no mention of the Lely Combi, which is far less cumbersome than the bridge link machines.

The Lely Combi is a very suitable, but slow, implement for carrying out combined cultivation and drilling and will provide a very good tilth with a reduction in the number of operations.

2 **Mr W W James** (Ryecote Wood College) On Mr Patterson's first table he referred to the work rates and energy requirements of the plough, shallow plough and chisel plough. Has he got some indication of the clod size which resulted from their use? Also I assume that when he said two passes with a tine, the work rate shown was for one pass?

The work rate was for two passes with the chisel plough and the values I showed were taken from our own experiements. Our objective is to provide suitable tilths from those different systems and we carry out photographic methods of recording which enable us to do careful studies and measurements. But we mainly use crop yield as an indication of the suitability of the tilth.

3 **Mr R I White** (Bidwells, Cambridge) I understand that farmers in Schleswig-Holstein have been forbidden to burn straw since about 1972 and have developed efficient ways of dispersing the straw through the soil profile. Mr Patterson mentioned the ability of the rotary digger to achieve this. Are there other suitable implements?

This is a very important question indeed and certainly the power driven rotary digger does provide good mixing of soil and straw to provide conditions for good decomposition, particularly on the heavier soils. On lighter soils the amount of inversion and incorporation would not be quite as good. With regard to other implements that might be suitable, I think that discs, particularly when incorporated in the Tillage Train, would be a way of incorporating surface straw to provide early decomposition after harvest. Another important implement would be the shallow plough with which to achieve incorporation and inversion of soil. The advantage of this implement would be very much higher work rates by contrast with conventional ploughs. With the shallow plough it would be very important to overcome the existing difficulties of penetration when operating in hard conditions. When one is using 8-10 furrows good contour following is also very important.

4 **Mr S E H Block** (farmer, Suffolk) One of Mr Patterson's tables seems to show that buring as a method of straw disposal was associated with higher yields than were the other straw disposal methods.

The results from ADAS trials and our own experiments show that the highest yields are usually obtained when the straw or stubble has been burned. The most severe yield depression occurs where the straw is in very close contact with the seed in large quantities as in some direct drilling situations.

5 **Mr N J Brown** (Rothamsted Experimental Station) Gordon Spoor emphasised the problems of wheels but I noticed that many of the combinations of implements which you illustrated had quite a lot of integral wheels, mainly for depth control. In the Tillage Train you had tines and discs and the situation where you had loosened the soil and then were compacting it again with wheels. I could not see any facilities for eliminating those wheel marks.

Under some conditions it is not necessary to work with the wheels of the Tillage Train lowered, the discs providing depth control for the tines. However, under many conditions use of the wheels for depth control is necessary but the second set of discs located behind the wheels loosen a proportion of the compacted area. Where farmers require wheel eradicators the manufacturer will provide them.

Questions following paper 4 (Dr H Traulsen)

1 **Mr P R Turney** (farmer, Cambridgeshire) Before lunch we were told that trials have shown yield reductions of between 9% and 20% of the next crop when straw is not burned. If this is so, much grain is being forfeited in Schleswig-Holstein.

Your trials may not be relevant to us. In 1972 when regulations were introduced which effectively precluded straw burning, we tried our best to change the law. We told the authorities that yields would be reduced and so on. We could of course, bale and remove the straw, but most of it, certainly in the eastern area, is chopped and incorporated. The outcome is not as serious as we had anticipated. It is essential to chop very short, spread evenly and incorporate thoroughly.

2 **Mr R A Mallet** (farmer, Cambridgeshire) Can I ask the speaker what were the factors leading up to the legislation controlling or preventing the burning of straw? We seem to be at that point almost in this country now.

In one very dry year we had 15 deaths as a result of road accidents caused by straw burning. As a result the legislation was introduced. I urge you to do everything that you can to prevent the introduction of such legislation.

3 Mr R R Gladden (adviser, Norfolk) The mouldboard plough differs from all other cultivating implements in that it repositions soil. On sloping land this can result in reduced depth of top soil on the top of slopes with increased depth at the bottom as a result of ploughing across the slope. Under such conditions a solution might be to plough up and down the slop. However, in countries with erosion problems this is virtually unheard of. In America advisory leaflets have been published on the subject for users of both reversible and conventional ploughs. What do you recommend in Germany?

If erosion is a problem, cultivators are preferable to ploughs. In Germany erosion tends not to be a problem but we still generally plough across slopes, but much would depend upon specific circumstances.

Questions following paper 5 (Mr J B Finney)

1 Mr G C King (Writtle Agricultural College, Essex) In some countries the disc plough is the most important implement for primary cultivation. Why doesn't it enjoy similar popularity in this country?

Under our conditions the disc plough cannot compete with the mouldboard plough largely because it is a less efficient inverter of soil. In those countries to which you refer where the disc plough is popular, it is used in the presence of rocks, stumps, etc, problems which we rarely encounter.

2 Mr T J Willcocks (NIAE, Silsoe) In Australia and the Sudan, wide, single gang discs are often used equipped with seed boxes. Does such a piece of equipment have a role here?

Equipment of this type was used in this country a decade ago without success. If you consider the arguments in favour of achieving complete seedbed preparation in a single pass, there is little to be said for using a single gang of discs. The low energy requirement of discs is a good reason for pulling two rows simultaneously whether they are tandem or offset.

3 Mr R A Jossaume (Fellow, Essex) Your diagram of offset discs showed the discs of the rear gang following exactly in line with those of the front gang. Am I correct in thinking that better coverage can be achieved if the following discs are offset by a distance equal to half the spacing of the leading discs? An additional advantage is improved coverage at moderate depth.

The illustration was shown just to indicate the general layout. I agree with your observation but I have often looked at tandem discs in the field and wondered if they do disturb the soil quite as completely as they should.

Questions following paper 6 (Dr D B Davies)

1 Mr R A Mallett (farmer, Cambridge) I am confused by the fact that the term "direct drilling" is used to describe systems of establishment which involve the use of such implements as the Paraplow.

I accept your point that if one is in fact cultivating the soil below seed depth then for that particular year it is perhaps incorrect to call the process direct drilling. But in such a case the justification for so doing is that the direct drill is used. However, so far as I am concerned, wherever compaction does occur, loosening is an essential part of the direct drilling technique.

2 Mr F W Blowey (farmer, Herts) Have you any experience of the vibrating subsoiler called the Shakaerator.

I have had a little experience of it but unfortunately we have not used it in any of our trial work. I am not an engineer but it appears to me that the Shakaerator can be adjusted to produce a range of conditions in the soil which is obviously very useful. However, at some of the demonstrations where I have seen it, I suspect that it was not working to its full potential for those conditions. On some sites where I have seen it working alongside other implements for loosening severe compacting in the top soil, it was bringing clods to the surface which subsequently would have to be broken down with discs, etc, therefore probably at the end of the day one would finish up with nearly as much compaction as when one started. I believe that in that type of situation the Shakaerator could have been adjusted to achieve a result which was much more like that achieved by the shallow-lift tools and the Paraplough.

3 Mr H A Thomas (ADAS, Cambridge) Were we to have a ban on the buring of straw, what changes would need to be made in cultivation strategy and what do you think is the biggest contribution which engineers might make in the next two or three years?

I would not have thought that most farmers would be prepared to go on baling their straw if there was any other means of dealing with it, because of the baling operation and the compaction which can occur in wet autumns. Therefore I think we have to look at what the Germans have learned about the incorporation of chopped straw. If we do incorporate chopped straw it inevitably means considerably more cultivations than we are now accustomed to. It also means that we have to use implements which can cope adequately with the incorporation of this straw. One which has been mentioned today which would probably deal with it quite satisfactorily is the NIAE Rotary Digger. I suspect that even if we could find implements with which to incorporate straw satisfactorily, without the consequent problems of decomposition we would get into all sorts of problems with the build-up of slugs. This would be a particular problem on the heavier soils and remember that about 50% of the soils on which cereals are grown in this region are heavy. One suggestion that has been made that engineers might consider is that if you are able to put the seed into the soil in the absence of the straw and then put the straw back over the top of it, as we have done by hand for two years now, one finds that the reduction in yield of the crop is minimal. A researcher had the idea of blowing the straw up into the air so that it came down behind the drill and hence the seed was in the ground and the straw was on the top. I do not know how much energy this would take and may be airborne straw is just as unpleasant to the public as airborne ash. A great deal of re-thinking would be needed if we could not go back to the mouldboard plough because of the problem of timeliness.

The mechanical farm of 2030

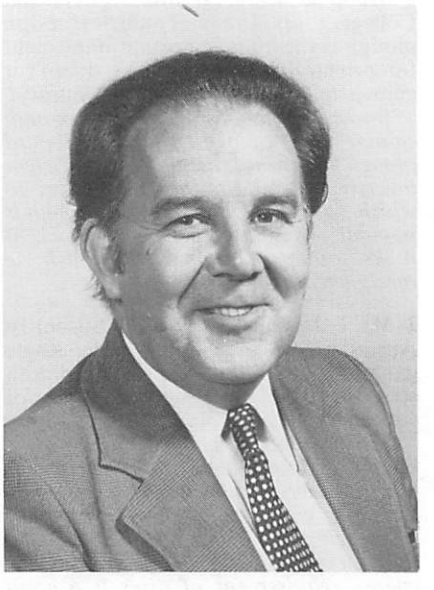
WHILST it is an accepted role for the researcher to look into the future, ideas so generated are only likely to become reality if the developer and the production engineer are aware that such ideas exist. Members of the Institution include all three categories and the following two contributions from the research world should stimulate much thought, discussion and perhaps, action.

The first contribution is part of a paper given by John Matthews, Head of Tractor and Cultivation Division at the National Institute of Agricultural Engineering to the 1981 meeting of the British Association for the Advancement of Science, and the second is by Brian Wilton, Lecturer in Agricultural Engineering at the University of Nottingham.

Both are concerned with replacing present systems of cultivation and harvesting on the grounds that at the moment we may be doing damage to the soil and that anyway the present systems are the product of the fast disappearing era of cheap fossil fuel.

When we think of changes which have taken place since the Institution was founded 37 years ago are their ideas really too far fetched?

J Matthews



Summary

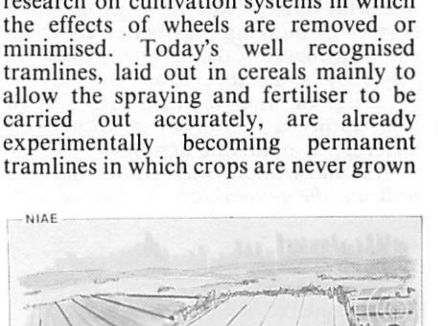
IN preparing this brief description of how a farm will look in the year 2030 I have made the general assumption that the rate of change will continue to accelerate. I am very conscious however that social factors, particularly the need within the country to retain, if not full employment, a high level of employment, could materially change this situation. It has already been publicly suggested that the farm labour force might be doubled or trebled to reduce unemployment and this must obviously affect the degree of mechanisation. On the other hand, the opportunities provided by technology will mitigate against this and one is very aware that, although certain technologies can be extrapolated from today, the next 50 years, if they are like the past 50 years, will produce totally new technologies that cannot even be envisaged in the early 1980s. I, therefore, make the excuse that these two factors will counteract one another and that mechanisation will continue to advance rapidly.

IT is useful to list four factors which I believe will influence the farm of 2030; these are social factors, preservation of the environment, animal welfare and the primary energy sources. Social pressures will continue to demand that increasing attention be paid to workers' environment, but with the ergonomics interfaces between men and machines being then more likely to be optimised for transfer of information than for the application of force or dexterity to controls. The rural environment will become an increasingly precious resource for the country as a whole, and pressures will surely increase to reduce odours, more carefully control agri-chemicals, avoid unnecessary loss of hedgerows and insects, ban straw burning in the field altogether and perhaps, most importantly, maintain the visual attractiveness of the rural landscape. Animal welfare will demand adequate space for animals to move, humane treatment and careful physical handling. Although I do not believe that there will be in 2030 a critical shortage of primary energy, I consider that electrical energy will be much cheaper than remaining portable fuels, and that this will, therefore, influence the agricultural power units. I believe that fertilisers will continue to be available with nitrogen probably produced from the atmosphere by electrically powered fixation and that the range of agri-chemicals will be much more selective and powerful in action, but, because no longer available from today's relatively cheap sources, extremely expensive.

The following description of the farm will almost certainly be wildly wrong. Prediction is extremely difficult bearing in mind the rate of progress of some technologies such as the silicon chip, whilst on the other hand the chisel plough took more than 20 years from its introduction to reach peak sales. I consider that farming will become even more specialised than today, and this paper deals only with engineering for arable crops.

Arable crops

Cultivation for arable crops is carried out for three main reasons; to create within the soil a structure with adequate air and water permeability and low enough resistance to allow roots to penetrate, to remove competing weeds either by burying them, destroying their root systems or removing them entirely, and to maintain a reasonably level surface for subsequent operations through to harvesting. Almost all weeds can be controlled chemically and by the year 2030 there will surely be no exception. On most soils the other two objectives, maintenance of structure and of surface, are necessary largely because vehicles have run over the soil and created problems since the previous cultivation a year earlier. This has already led to much discussion and a significant amount of research on cultivation systems in which the effects of wheels are removed or minimised. Today's well recognised tramlines, laid out in cereals mainly to allow the spraying and fertiliser to be carried out accurately, are already experimentally becoming permanent tramlines in which crops are never grown

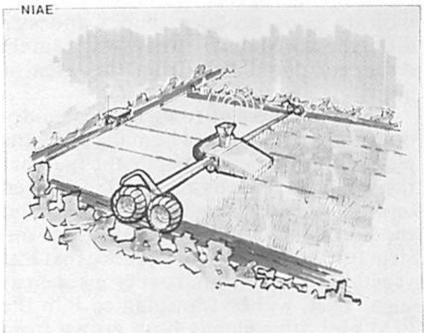


J Matthews BSc FInst P FIAgrE is Head of Tractor & Cultivation Division, National Institute of Agricultural Engineering, Silsoe, Bedfordshire.

but with which wheels may be kept entirely from the growing surface. If this is done with day's vehicles then wheel marks are necessarily many; also these vehicles all have different wheel sizes and track widths. By 2030 the crop spanning gantry will have solved this particular problem. This gantry will probably span 15-20 metres of crop, its wheels perhaps travelling on the surface of the porous 'backfill' of stones or synthetic material installed as part of the drainage system of the field. Headlands will be unnecessary since the 360° steering of the gantry permit it to travel sideways without turning to take up its position for the next bout. A minimal sacrifice of area will be needed only in badly shaped plots, these areas being taken up by planned planting of trees or shrubs for wind protection and for environmental improvement. Only one wheel mark is necessary for each strip of crop and, although the gantries conceived today are thought of mainly as being limited to spraying and fertilising, cultivation and harvesting will be possible by then.

Much of today's cultivation is still carried out at 200 mm depth. Without wheels it will be possible to maintain such an accurate surface that 50 mm depth will be practicable and adequate. Our evidence at NIAE is that the soil resistance and hence energy needed in cultivation will often drop by as much as 50% when wheel effects are completely absent. The combination of shallow working and absence of wheel effects thus suggests that power for cultivation with the gantry may be only about 12% of today's power level, and with the good traction conditions on the backfill, the vehicle may be made to operate with an efficiency very much higher than today's tractors, where up to 40 or 50% of the power is often lost in wheel slip and rolling resistance. One can thus see that for the cultivating process the power required may be only 5-10% of today's levels.

Cultivation may however be limited to vegetables, other root crops, and specialist crops since we may well have reached the stage that we do not cultivate at all for cereals. The possibility of a mechanical dibble planter with a high enough work rate and an ability to separate cereal seeds, fast and accurately enough to direct drill cereals with precision — say on a defined grid — has been a gleam in the researcher's eye for several years. By then the problem will be well solved and two possibilities will exist. Firstly, a hybrid cereal may be bred which requires one seed to be planted perhaps 'on the square' at 100-200 mm intervals. This will then develop many tillers to be essentially a bush. The other alternative is that plants remain like today's wheat or barley, but that we are able by dibble processes to place one seed at the right sort of depth on a 40 or 50 mm square. The most suitable soil structure for cereal planting probably exists just prior to harvesting the previous crop. If we have no wheel to consider it is still not inconceivable, despite the obvious complexity of the dibbling mechanisms, that this be propelled through the standing crop and that the new crop be planted and allowed to germinate before the previous crop is harvested. Whatever the method of planting, it is always an advantage to plant the seed at an optimum depth dictated by soil moisture profile. If the surface is now level and the structural profile near ideal, then the machine is almost certain to have an automatic soil moisture monitor which varies the depth of seed insertion so that they are placed at the shallowest point at which the soil moisture content is sufficient for rapid germination.

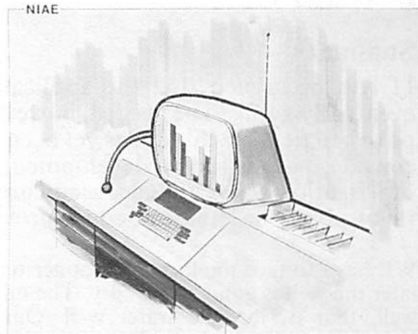


The operator of the gantry — I refrain from calling him the driver because he will probably not steer or turn the machine — will be provided with sophisticated displays showing the amount of seed planted, its depth and something about soil conditions. This will be desirable since it will still be important that in this extremely complex environment, he be able to make some judgements. Steering will be carried out with reference to buried cables within the wheel tracks and control of the mechanism on the machine in relation to forward speed or during turning, together with detection of faults will be the subject of automatic control loops. As well as seed planting, this will be vital in the following processes of fertiliser addition and of treatment with protective chemicals. The gantry, of course, provides a much more stable distribution mechanism than a spray boom or distributor on today's tractor, with its motions over rough agricultural surfaces. On sloping land the presence of the slope will be taken into account by on-board computer and the distribution pattern appropriately corrected. For ease of handling it seems probable that fertiliser will be used in liquid form but that distribution will be from only a few centimetres above the ground on the more accurate surfaces so that losses such as run-off and drift, will all be much less important risks than they are today. Everything that is dispensed from the gantry will be recorded on indicators and on cassette or magnetic strip card which will be fed into the farm management computer at the end of the day.

Every few years fertiliser and trace element concentration in the sub-soil will be maintained by inserting liquid chemical formulations throughout the soil to a depth of a metre with a narrow vibrated tine. To further reduce draught the tine will also be lubricated by the liquid formulation (made up as a polymer) flowing through holes in the surface of the tine. Amounts of fertiliser added will be continually controlled in relation to continuous monitoring of levels in the soil.

Either the general purpose gantry, or possibly a more simple version, will be available during the growing stages to irrigate, this time with completely automatic controls and no operator present. Irrigation will be in response to decisions made by the management computer and this will be dealt with later.

Harvesting does appear to present a problem to those of us used to today's bulky combine harvester and a fleet of tractors and trailers conveying the grain, and perhaps subsequently bales of straw, from the field. The answer lies in whole crop harvesting. This is today only an experimental system but it does have certain inherent advantages which may increasingly lead to it being attractive. For use with the gantry farming system, the mechanisms carried across the plots are minimal, being restricted to means of cutting and chopping the crop, and collecting it to be carried off the fields. A cutter table can be mounted on the gantry although it might be that the gantry will need to traverse the same strip on three or four occasions to cover its whole width in cutting. A chopper harvester will not be an excessively bulky component, and crops when cut may be stored in modular containers mounted on the gantry and mechanically transferred to special carrying vehicles at the ends of the bout.

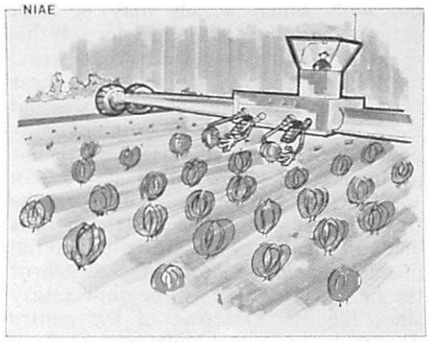


At the farmstead, or factory, threshing and drying will follow. In 2030 threshing may well be by the application of ultrasonic energy rather than the mechanically inefficient beating and scraping to which the crop is subjected today. Two possibilities can be foreseen for the subsequent drying process. In the first, a proportion of the straw and waste material from the heads is employed as an energy source to fire a hot air dryer. More innovatively, drying might be carried out with microwave energy with the advantage that moisture loss is so rapid that berries crack as a first step also in the milling and feed preparation process for the grains.

Inevitably, both the threshing and drying processes will be subject to electronic monitoring and automatic control, the threshing to maximise material throughput without gaining unacceptable losses of berries in the reject material, and the drying to ensure a uniform moisture content with a minimum of energy and yet no under-drying. Today's developments of infra-red reflection or microwave absorption methods of moisture determination could well by then still be the most convenient and accurate methods.

The vegetables or sugar beet crop will also be largely processed off the field but the field harvesting process is inevitably fundamentally different to that for cereals. It is probable that, with such uniform soil and moisture conditions and attention to ripening uniformity in the crop breeding, lettuce and cauliflower crops will grow such that all plants are ready for harvesting at the same time. If they are not, however, development and application of selective harvesters will present less problems than today. Choice of plant for harvest is based mainly on bulk, and this can either be sensed by pressure controlled mechanical feelers, by the transmissivity to x-rays or microwaves, or possibly even by passing plants between electrical capacitance plates. Cutting the stalk is likely to be a task for a thin fixed wire, or perhaps a high speed rotating wire like the garden "Strimmer". Compared with these methods the laser appears to be a relatively expensive and low-efficiency method. Subsequent sorting and grading of vegetables or fruit produce will increasingly be carried out in larger scale pack houses to permit the more sophisticated but rapid techniques of monitoring. Bruises might, for example, be detected using thermography, which preliminary work already suggests can differentiate between a bruise and an unblemished region of an apple which has previously been cooled and is subsequently warming a few degrees. Sophisticated, but in 2030 inherently cheap, methods of pattern recognition based on microprocessors will be able to indicate poor produce shapes and size differences. Manual work will surely disappear completely from this area of activity.

One final area of rowcrop husbandry on which comment will be made concerns plant establishment. Despite the fact that the general soil environment has been improved by the removal of wheels and the more careful maintenance of soil structure and moisture, I believe that leaf vegetables and certain root crops such as sugar beet, will be transplanted into the field plot after having been grown from



seed within a covered environment. Completely automatic transplanting of batches of plants grown initially in modular containers, is of course, already possible. In 50 years further mechanisation and faster processing of the soil block production, and the transfer of soil blocks to the transplanter, will overcome some of the marginal economic restrictions that apply to this technique today.

Centre pivot cultivation: Is going round in circles the way ahead?

B Wilton

Summary

IT can be argued that the application of electrical power to field work is eventually going to be needed, however no entirely satisfactory system of taking power to field machines has yet been developed. One system that may be worth considering is based on developments in irrigation techniques: the distribution of irrigation water and electricity are compared and it is suggested that centre pivot power distribution could provide an answer to the problem.

WE have to face the fact that sooner or later the well is going to run dry. The oil well, that is, not the water well. Our industry will no doubt find a way to live with reduced supplies of liquid fuels, whereas finding a way round the problem of the world's water wells running dry would be much more difficult.

In countries with surplus grain there is much current interest in on-farm production of alcohol, but just how far this line can and indeed ought to be followed while other people are starving is debatable. The same may also be said about the growing of crops to provide vegetable oils to fuel diesel engines, even though by-products that can be fed to animals may emerge from such a system. Liquid fuel from coal is more defendable, but coal supplies are not inexhaustible.

One possible solution to this problem would be to switch to electricity and perhaps as agricultural engineers we ought now to be considering the implications of such a change. Just how the electricity would be generated would be for others to decide: coal in the short term perhaps maybe we will 'go nuclear' with the French or, hopefully, we will see the development of generation systems that use tides, waves, winds or some other 'clean' and renewable source of energy.

Field electrification

In the UK some 5% of agriculture's on-farm, direct requirement for energy is supplied by electricity. The ways in which it can be used are well-established and although there are developments and new applications coming forward all the time that will undoubtedly increase consumption in agriculture, any major change in this situation seems unlikely unless some means of using electricity for field work is devised. Several attempts to use electricity in this way were made more than 20 years ago, but as far as is known the approach used at that time is not now being followed up — presumably the difficulty of working with trailing supply cables is the main reason for this. Another ingenious approach was suggested 14 years ago by Reece[1] who envisaged the installation of tracks on field boundaries from which electrically driven winches could pull equipment backwards and forwards across fields. Reece suggested that these structures could be made to carry irrigation and drainage waters and that they could form the basis of a transport system along which material could be moved to and from the field. Again, as far as is known, this idea has yet to be put into practice.

Whether the lack of progress in field electrification is due to technical difficulties, high installation cost or the lack of need to move away from the diesel engined tractor is impossible to say, however the last of these three alternatives seems the most likely. However situations change and it could well be that in a few years a more positive move towards field electrification may be required.

In many ways the sites on which crops are produced would be appropriate

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candidates for the kind of approach to power distribution now mainly confined to manufacturing premises: the sites are permanent, the operations are repetitive with many being suitable for automatic control, and the pattern that moving machines need to follow can be laid down and seldom changed.

Water and electricity

When children are first taught about electricity the idea of water moving along pipes is sometimes used to convey the concept of electricity flowing along wires. Pressure is compared with voltage, flow with current. It is an interesting exercise to extend this sort of comparison to irrigation systems and possible power distribution systems.

The last few years have seen major developments in methods of irrigating: sprinkler systems have in many cases been replaced by hose reel machines and in some parts of the world centre pivot equipment is taking over. Literally thousands of centre pivot installations are now in use, mainly in the USA, Africa and the Middle East; they have now started to appear in the UK where at the time of writing it is understood that four have been installed. It could be argued that sprinklers can be likened to a fixed electrical wiring system with numerous sockets or take-off points and, to continue the comparison, hose reels are basically similar to trailing cable and winched systems. Why not, then, consider the electrical counterpart of the centre pivot, indeed what is there against the idea of combining the two?

Centre pivot cultivation

The preferred method of driving the supporting wheels on centre pivot units is to use electric motors, the supply being taken to the boom through slip rings. One development might be to reinforce this supply, stiffen the boom, fit larger motors and let the boom act as a traction unit. With this arrangement any implement being towed could be made to move along the boom one width per revolution. The radial movement could presumably be made either continuous, giving a helical pattern of work, or intermittent to give a series of concentric circles.

Although this approach would probably be technically possible, a cheaper solution would almost certainly be to use the boom simply as a cable carrying/steering/controlling unit and to have a multi-slung cable to take a supply to motors on the implement. These could then have drive wheels and/or the equivalent of power-take-off driven components. Spraying and the application of liquid fertilisers would also be possible and this could be done with a spray boom which moved along the main boom automatically, complete with its own supply hose, just like the electricity supply.

Harvesting, of course, is an entirely different matter. Who says so? Why? With a little ingenuity it might even be possible to fit harvesting operations into the centre pivot configuration. Is it just possible to imagine an electrically driven harvester discharging potatoes, onions, grain, forage or peas onto a lightweight belt conveyor that carries them to the centre? Delivery would be into a conventional tractor and trailer, of course — mustn't let the imagination run too far. Can't be too revolutionary.

Let us assume that it would be possible to cultivate drill, fertilise, spray, irrigate and harvest crops from a boom. Field shape would have to change from square, rectangular or irregular to hexagonal, but why shouldn't it in some areas, after all in some other countries they have adapted to the idea of farming in circles. Our own ideas on the pattern and organisation of field work haven't really changed much from the days of the ox. In other sectors of his activities man now has re-usable space shuttles, instant global television and nuclear reactors — all developed in the last 50 years. In 50 years will our industry still employ men to drive tractors in nearly straight lines up and down fields; will we still have headlands, tramlines and markers? No doubt we will, but it is also just possible that we will have some circular fields with the awkward in-between bits used as sites for both the windmills required to provide power and cover for the pheasants.

Reference

1 **Reece, A R,** (1968). An automatic electric farm. *Farm Mechanisation and Buildings,* 20.266.18.

Book

Biomass

WHEN asked to review the first issue of *Biomass an International Journal* I wondered which niche the publication was to fill. The introduction tells me that it is "essentially concerned with the use of biomass as an alternative energy source".

Thus fortified I proceeded to the first of six articles, "Biomass through the Ages". This was a gentle resume of the history of wood burning, ethanol and biogas. Written more in the style of a Sunday colour supplement than a scientific paper I cannot imagine who would use it as a reference.

The second article was on "The role of Fundamental Biological Research in Developing Future Biomass Technologies" and was as turgid and long winded as the title suggests. It gave me the impression of proposing research for research sake and didn't convey to me what the key areas of research are likely to be.

Article three on "The Development of Biogas Utilisation in China" was political rather than technical or scientific. Article four was about volatile fatty acids in anaerobic digestion and whilst interesting could have appeared in a number of other journals.

The last two articles concerned the study of an Indian village ecosystem and the analysis of the study results. It showed that a lot of the traditional practices make sense and clearly identified areas for improvement, and also showed the integrated approach needed for any successful use of biomass. However, these articles have already been published as part of the proceedings of the first EC Conference on Energy from Biomass!

On the evidence of this first issue I doubt whether we need *Biomass,* international, or otherwise.

Biomass an International Journal from Applied Science Publishers Ltd, Barking Essex, England

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