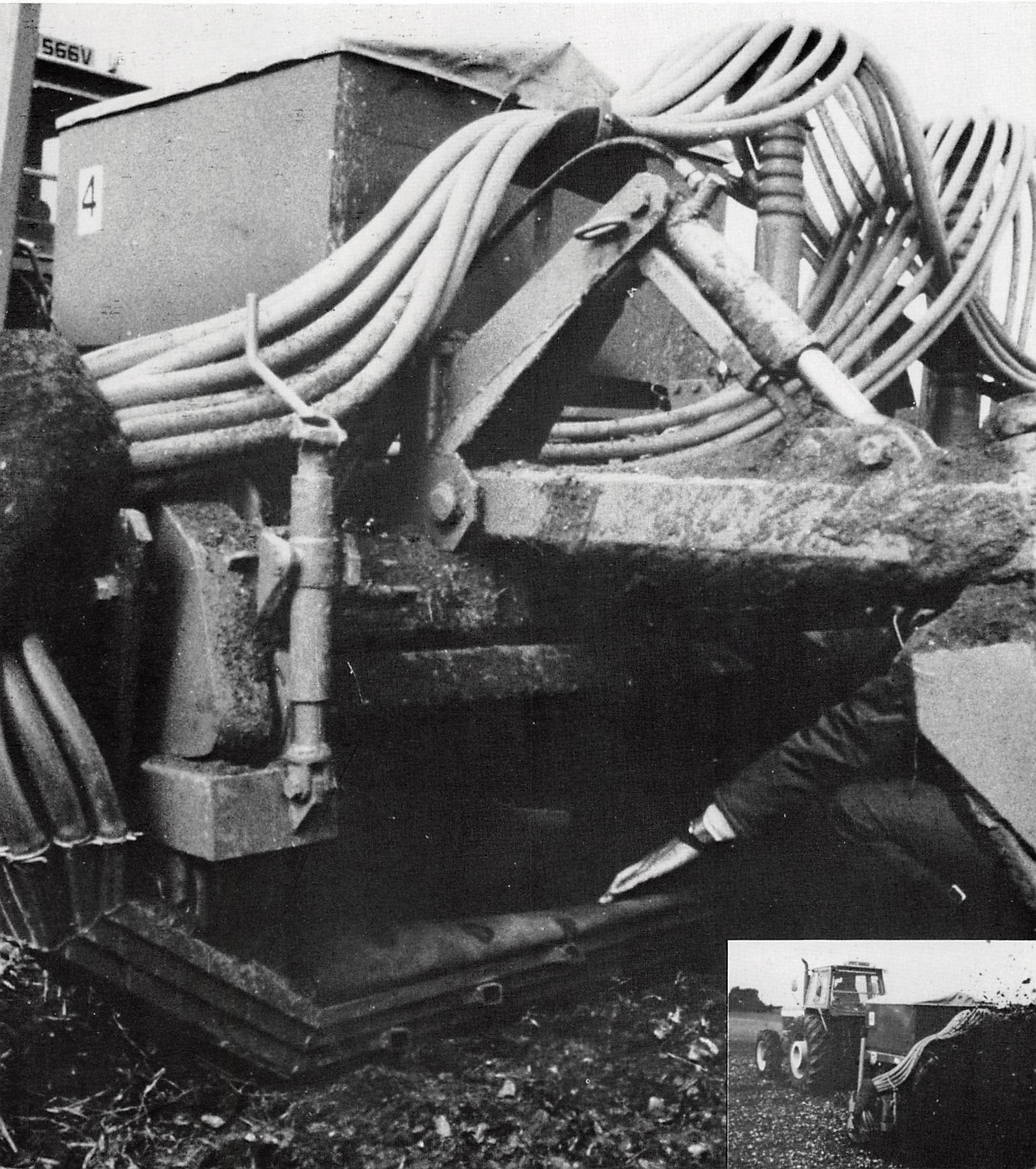
THE AGRICULTURAL ENGINEER

Volume 38, Number 4

WINTER 1983



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The Horsch Accord solid seeding direct drill spreads combined straw, stubble, soil and fertiliser (thrown up by the cultivator blades) over seed metered from individual delivery tubes in a cultibar at the rear of the machine.

[ESCA 'photo]

THE AGRICULTURAL ENGINEER is published quarterly by the Institution of Agricultural Engineers
West End Road, Silsoe, Bedford MK45 4DU
Tel: 0525 61096

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

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ISSN 0308-5732

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Editorial: communications

SINCE taking over as Honorary Editor last year, it has been agreed by Council to restrict the number of conferences which are organised by the Secretariat and to encourage individual Branches to arrange local events. This has important repercussions for THE AGRICULTURAL ENGINEER. The reduction in copy from the Proceedings of our Learned Society introduces editorial opportunities for change and a fresh challenge to Members.

There has been criticism that conference attendees receive little new when a Journal issue is devoted solely to the proceedings, two or three months later; there has been criticism that there is not a sufficient spread of interest in a single issue when three or four papers are devoted to a special topic; and, of course, there has been criticism that the material is dated before it even goes into print.

As a counter to this criticism, material from Branch conferences could well appeal to a wider readership, for only a small proportion of our Membership are within reasonable commuting distance of these regional centres. Unfortunately, the greater dependence of the Branch events on a farming audience encourages a strong commercial flavour often to the detriment of adequate documentation. Speakers should be encouraged to prepare papers or, alternatively, perhaps the Branch Press Officer could prepare a conference review.

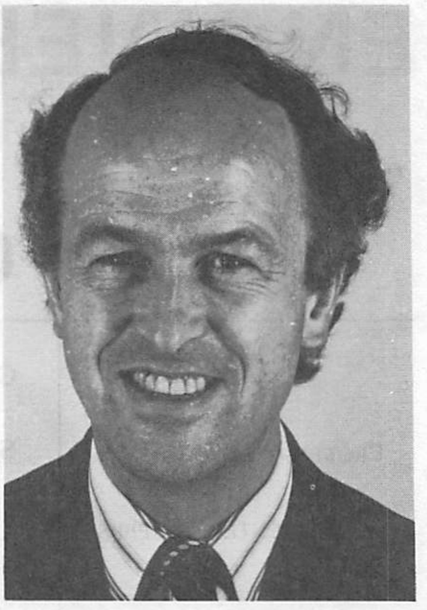
We already have a blend of refereed research papers and technical/mechanisation articles. There is, however, almost a total absence of any commentary on product development and marketing from commercial sources. Communications within some disciplines have been fostered through the formation of Specialist Groups in Crop Drying and Storage and in Drainage. We hope that they will continue to generate, within the Specialist Group, the enthusiasm which ensures a steady flow of publications through the Journal.

A further outlook for shorter articles was introduced in this issue under the section headed "AgEng Items". As an *aide-memoire*, ITEMS is an acronym for Industrial, Technical, Educational and Mechanisation Summaries.

Many technical innovations in equipment are only superficially presented as a product release. Many research and development investigations receive inadequate publicity either because the work, in itself, does not merit presentation as a complete scientific paper, or because the preparation time for a full report is not available, or simply because of a shift of emphasis in the programme. Student projects are a valuable source of data which is not readily accessible — these include reports prepared for the Higher Diploma in Agricultural Engineering, Honours Dissertations in Mechanisation, even MSc and PhD theses which are never formally written up and published. Project summaries and mechanisation notes are prepared for demonstrations which can be attended by only a proportion of the Membership.

AgEng Items seek to fill the void between consumer orientated articles on machines and filed patents; between internal reports and research papers. Short articles of 800–1200 words should include background to the work, a description of the results or innovations, and the conclusions of the investigation, together with a photograph or figure related to the project.

The Editorial Panel and the Secretariat have also devoted considerable time and energy to prepare a datafile of the Subject Index of material published in the Journal over the past 10 years. The application of computer technology will greatly simplify annual updating of the Subject Index and alphabetical listing of the Author Index. The 1973–82 indices which appear as an insert in this issue are not simply an historical record of past endeavour. The omissions in the Subject Index are equally important as a planning aid for future issues and the paucity of attention in such areas as Land Reclamation is an obvious challenge.



Brian D Witney

The Instructions to Authors have been revised and are reproduced at the back of this issue. These are not intended as a deterrent; attention to the detailed instructions saves editing, correspondence and frustration. We wish to produce a publication that attracts your attention and that you enjoy reading.

Make the Journal reflect the needs of our Membership through more awareness of work in hand and more information on advances in machine design. We welcome *your* involvement in *your* Journal.

BDW

Soil management or reclamation?

G Spoor

1 Introduction

A GOOD soil physical environment is a prime requirement for high levels of crop production and this is synonymous with good soil structure and subsurface drainage. Such a condition provides an appropriate pore size distribution, optimising available water and aeration status and helps provide adequate temperatures with minimum impedance to root development. Soil management is concerned with maintaining and hopefully improving this environment, but in the process, two opposing sets of forces are at work, one group tending to improve structure and the other causing deterioration.

Soil structure improvement arises largely through plant root and soil organism related activities and natural weathering. Roots through their growth, exudates and breakdown products coupled with organism activity, are responsible for the formation and stabilisation of the larger conducting pores and structural units throughout the soil profile. Mechanical operations can assist in exposing soils to the weathering agents and in the formation of the larger pores but can do little for their direct stabilisation.

The forces causing soil structure deterioration are related to those activities which encourage the oxidation of organic matter, aggregate destruction through mechanical or chemical means, and restrictions to root development through impeding layers and general compaction. The deleterious activities are frequently associated with many farming operations including soil tillage and harvesting, traffic, poor drainage and irrigation as well as rainfall impact on bared soil surfaces.

This paper reviews past and current soil handling practices in the light of future requirements for the maintenance and improvement of soil structure. Possible beneficial changes to the management pattern are discussed and their implications for the designer, researcher and farmer considered.

2 Past and current approaches to soil handling

The reasons behind many current practices in an industry with such long traditions as agriculture can be revealed by reviewing past approaches to soil handling and management. Such a review also provides a good base for considering future developments and requirements.

2.1 Soil handling pre 1960 in Britain

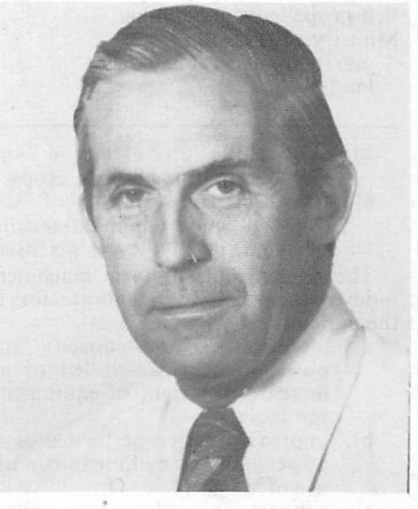
The initial method of cultivation based on a digging stick or hoe was extremely precise, with soil only being disturbed where absolutely necessary, largely for the control of weeds. The introduction of animals as a source of power and the mouldboard plough for weed burial, changed this precision tillage into a form of complete tillage. Adequate burial could only be achieved through deeper working at 50 - 100 mm depth and complete soil surface inversion. The deeper tillage resulted in the formation of clods and hence the need for subsequent operations for seedbed preparation arose.

The ideas and practices developed by Jethro Tull in the 18th century led to a considerable increase in the amount of complete tillage, based on the premise that production increased with increased soil working. Soil preparation now took the form of ploughing and cross-ploughings, followed by multiple harrowings and often inter-row hoeing. These practices continued well into the 20th century.

Interest in deeper tillage, to depths of 500 - 600 mm, usually linked with subsurface drainage increased in the 19th century, but the practice was never widespread and ceased abruptly as agriculture entered the depression at the end of century. Protagonists of these practices such as James Smith of Deanston and the Marquis of Tweeddale, attributed the improved crop response as much to better drainage as to greater rooting depth.

The introduction of the tractor in the 20th century did not change soil handling methods, although ploughing depths tended to increase. Yield responses to deeper working were very variable and where positive, were largely attributed to better weed control (Russell 1956).

During the whole of this period, from the introduction of the mouldboard plough by the Romans to the late 1960s a system of complete uniform tillage was practised with effectively random passes of animals, tractors and implements across the fields. Crops were established largely in the spring, allowing plenty of time for soil weathering following autumn ploughing. Although tillage was frequently excessive, the major benefits came from weed control, and weathering played a major role in conditioning and restructuring structurally damaged soil. The power available for soil movement was low and hence soil conditions themselves played a large part in dictating whether soil working was possible. Soil loadings over the period were relatively low, see table 1, and the results of comparative tillage depth studies, Russell (1956) and of compaction studies, Soane (1970) and Eriksson *et al* (1974), show that most of the soil damage resulting from the farming operations was confined within the plough layer. This damage was alleviated annually through ploughing and weathering action.



2.2 Soil handling post 1960 in Britain

During the 1960s the rate of technological change started to increase rapidly, the changes being initiated by economic and research development factors. The major changes which influenced soil handling practices were:

a) large increases in yield potential of crop varieties;
b) increased fertiliser, pesticide and herbicide usage;
c) introduction of paraquat;
d) reduction in farm labour force;
e) increased power available;
f) change from farmyard manure to slurry;
g) closer links between producers and processors.

These changes stimulated:

a) rapid increases in yield in many crops and in the quantity of materials to be handled;
b) increases in crop inputs eg fertilisers and herbicides and in the timeliness of their application;
c) movement towards autumn drilled crops and earlier and shorter establishment periods;
d) increased stocking rates and longer grazing season;

which resulted in:

a) harvesting time dictated increasingly by crop growth stage rather than soil condition;

Inaugural Professorial Address presented at the National College of Agricultural Engineering (now Silsoe College) on 3 March 1983 by Gordon Spoor, Professor of Applied Soil Physics, Cranfield Institute of Technology.

Table 1 Size of farm equipment

	Power, kW	Mass, t	
		1970	1983
Wheeled tractor	26	2	
	60	3	
	150		10
	200		12
Combine (full tank)		6	15
Trailer		5	15
Manure spreader		4	10
Potato harvester (tanker)			10
Self-propelled slurry tanker			25
Ministry of transport maximum allowable axle load		11	

Table 2 Yield of extra long staple seed cotton — Gezira Scheme, Sudan

Period	Yield, kantar/feddan
Average yields	
1935–1954	4.2
1954–1971	4.6
1971–1975	4.3
Annual yields	
1976	2.7
1977	3.6
1978	4.0
1979	2.9
1980	2.5
1981	2.1
1982	3.7

b) reductions in effective soil weathering time between crops;
c) increased importance of soil physical conditions in influencing output as fertility levels increased.

The response of the farm machinery industry to all of these changing factors in the agricultural scene was to:
a) increase machine capacity and power further which led to an increase in weight of equipment, see table 1;
b) improve tractive performance of power units by making maximum use of weight;
c) support the additional weight, particularly on implements, on high pressure, high ply-rating, relatively small diameter narrow tyres;
d) introduce specialist processor inspired machines, frequently designed with little thought for soil conditions.

The net effect of all these changes from the soil point of view can be most clearly seen by following the developments and experiences in the direct drilling of cereals on the well suited soils, which started in the early 1960s. Initially the results were very encouraging with equivalent and sometimes higher yields than from traditional tillage systems (Davies and Cannell 1975). Continuing improvements were noted in pore size distribution, organic matter levels, surface tilth, soil structure and soil support capacity (Russell *et al* 1975). After a period, however, compaction symptoms started to appear, coinciding with significant increases in machine contact loads and pressures. The soil, even in its undisturbed state, was now no longer capable of supporting without unfavourable deformation, the surface loads.

An increase in soil problems was also experienced over the same period in the root crop growing areas, resulting in the increasing abandonment of these crops on the heavier soils. Whilst soil damage was not the only reason for a cropping change, these soils were the first to suffer from the more punishing loads, with farmers finding increasing difficulty in rectifying the structural problems created. Similar compaction problems have also arisen in intensive grassland areas, where stocking densities, and the weights of forage and slurry handling equipment have all increased.

This period has therefore seen a very large increase in soil loading and a move from initially satisfactory zero tillage to a situation where there is increasing interest at both farm and research level in the possibilities of deep tillage for the future.

2.3 Soil handling worldwide
Similar developments in tillage and machinery practices have taken place in many parts of the world, the major difference being the time scale, with certain areas still practising precision tillage and others strip tillage with animal drawn equipment.

Water application practices in the continuously irrigated areas have varied between locality and with time. Their effect on the soil in many areas has, however, been similar, namely, the development of waterlogging or salinity problems sooner or later. Current reports from California suggest the more recent highly efficient trickle systems are no exception. To illustrate the extent to which these problems can develop, in the Lower Indus area in Pakistan alone, 17.5% (1.25 million hectares) of the cultivable area is predominantly saline with a further 39% (2.8 million hectares) suffering from saline patches (FAO 1971). Effective drainage could prevent these problems, but at present most of the current drainage activity in irrigated areas around the world, is directed towards the failed drainage systems.

Long standing highly successful existing schemes are under continual and increasing pressure to achieve greater production. The consequences of this in a number of cases has been very serious, for example the rapid decline in productivity within the Gezira Scheme in Sudan, illustrated in table 2. Part of this decline can be attributed to a deterioration in soil conditions resulting from a significant shortening of the fallow period that is so essential for improving the soil physical conditions (Jewitt 1956).

The consequences of soil erosion have been well known for many years and great efforts have been put into combating the problem. Attention has, however, tended to concentrate more on methods of trapping soil once the soil has started to move, than on measures to prevent detachment in the first place.

3 Future soil management options
The brief review of past and current soil handling practices highlights the emphasis placed on management measures to overcome problems, rather than attempt to prevent the problems arising in the first place. The options open for the future are therefore to either continue this reclamation management approach, or to move towards preventative management.

In the tillage/mechanisation area the damaged soil zones have until recent years been confined mainly within the top 300mm of soil. This has allowed the annual reclamation process of tillage plus weathering to alleviate most problems. Any continuation however, of the current machinery trends with increasing loads, will increase the depth and degree of compaction damage, making reclamation increasingly more difficult and expensive. Figure 1, taken from Eriksson *et al* (1974), shows the increases in vertical soil deformation at depth that

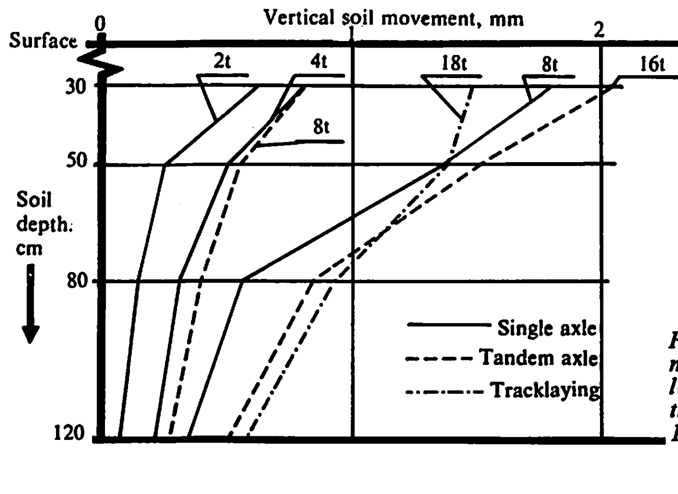


Fig 1 Vertical soil movement under loaded wheels and tracks (After Danfors, 1974)

can be expected from higher surface loadings even at the same contact pressures. The situation has already arisen on many farms, as shown in Table 1, where the axle loadings on a material, namely soil, which the civil engineer removes immediately as being unsuitable for a road, exceed the permissible loads on a carefully prepared road pavement.

The results from continuing Swedish work (Hakansson 1980) on the natural recovery of deeper compacted layers, suggests that compaction effects could last for decades. Virtually no alleviation of compaction within a layer between 350 - 450 mm depth had occurred over a two-year period, despite the soil freezing annually to depths well below this. The principles and techniques for satisfactory soil loosening at depth are established to enable deeper reclamation to be executed (Spoor and Godwin 1978) but loosening alone does not immediately rectify structural damage. The continuation, therefore, of this reclamation form of management in the future must be seriously questioned, for even without deep compaction problems, the annual ritual of loosening soil for the pleasure of recompacting it again, makes little sense if it could be avoided. Any move towards a system of preventative management will require a reduction in the magnitude of the punishing loads and pressures applied to the soil. Such a change will almost certainly involve a cost and hence it is worthwhile considering the potential benefits which may be achieved from preventative management to weigh against this cost.

4 Potential benefits from preventative management

The possible benefits arising from control over the level of soil compaction and traffic can be categorised as follows:

1) avoidance of yield depressions resulting from incomplete reclamation;
2) yield increases as a result of an improved soil environment;
3) reduced establishment costs and increased system capacity;
4) increased working period;
5) opportunity for precision tillage.

The yield depression of the following crop resulting from incomplete reclamation can vary widely depending upon the level of damage remaining and the subsequent weather conditions. Figure 2, taken from Hakansson (1980), shows equilibrium yield depressions resulting from medium size farm vehicle compaction every autumn prior to ploughing over a 10 year period in Sweden. The compaction effect was mainly restricted to the plough layer and an elapsed time of 5 years was required after the experiment to alleviate all the damage done. Continuing yield reductions are also being recorded, following compaction damage to 500 mm depth which was created through one concentrated wheeling treatment with a 16 tonne tandem axle trailer (fig 3).

Whilst it is recognised that there is an optimum degree of compaction for crop production, deep loosening experiments without subsequent recompaction by wheels, give some indication of the potential for yield improvements, see table 3 and Stephens (1855), McEwen and Johnson (1979), Rowse and Stone (1980) and Gooderham (1976).

Table 4, derived from Patterson *et al* (1980), shows the influence of working depth on the cost and system capacity when establishing winter cereals. The significant penalties from deeper soil working to overcome deeper compaction can be clearly seen.

Spoor and Godwin (1978) and (1979) have shown that soils can be effectively loosened at moisture contents well in excess of those commonly considered as limiting, providing confining stresses are low. Table 5 shows brittle or loosening failure occurring in triaxial compression test samples at moisture contents well above the plastic limit. With traffic control, therefore, the opportunity exists for increasing work days and timeliness, extending crop growing seasons and extending root crop production to the heavier soils.

The current approach to crop establishment executed with random tractor passes, is completely dominated by the action of the wheels or tracks. The tractor wheels continually modify the soil condition produced by the implements,

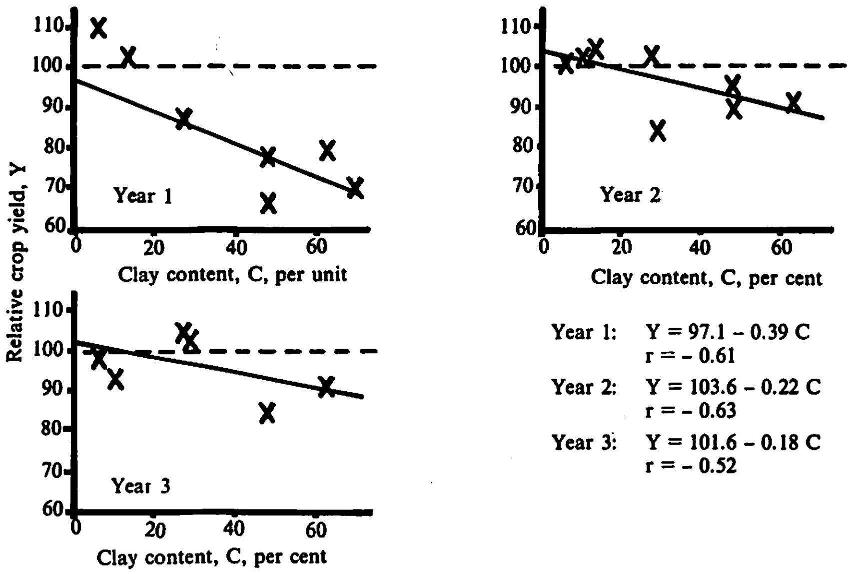


Fig 3 Yield reductions in successive years following compaction damage at 500 mm depth (After Hakansson, 1980)

Fig 2 Yield depression following soil compaction during previous harvest

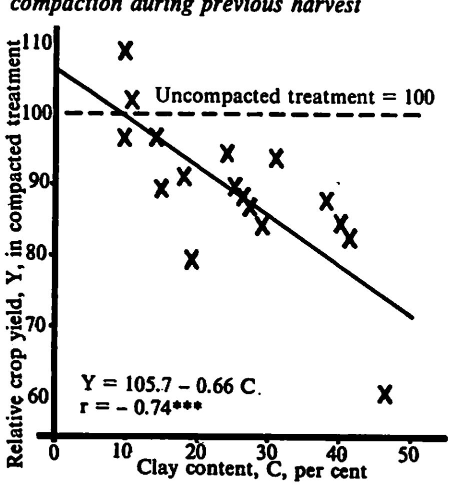


Table 3 Crop response to deep soil loosening

	Crop response, % yield increase	
YESTER 1850 (Clay)		
	Drainage only	*Drainage and deep loosening*
Cereals	35	95
Turnips		100
ROTHAMSTED (Sandy loam)	*Deep Loosening*	
Cereals	20–25	
Sugar beet	11	
Potatoes	0	
WYE (Silt loam)		
Cereals	15	
WELLESBOURNE (Sandy loam)		
Potatoes	0	
Broad Beans	25–95	
Red Beet	3–20	

Table 4 Relationship between cultivation working depth and cost of establishing cereals

Cultivation depth, mm	*Relative Cost*	*Relative output, time/unit area*
0	1	1.0
100	0.9	2.0
150	1.3	3.5
200	1.8	4.0
400	2.8	7.0

(data derived from Patterson et al 1980)

Table 5 Effect of soil moisture tension on type of soil failure at low confining stress

Soil type	*% samples failing in brittle manner*				*Moisture tension at plastic limit, bar*
	Moisture tension, bar				
	0.05	*0.16*	*0.50*	*1.00*	
Wicken Series Clay	0		37	90	2
Fladbury Series Clay	12	50	100	100	9

tending to increase the degree of compaction at each pass. This could well be a major reason for the lack of significant differences between implement and no tillage treatments in many tillage experiments. Control over the dominating wheel opens up the possibility of returning to precision tillage. Particular attention can then be paid to providing optimum but different conditions in various parts of the field and the soil profile for the seed, the roots, wheel support and traction and the conversion of water and soil. Figure 4 illustrates from the work of Prestt at the National College of Agricultural Engineering, the type of yield improvement possible from providing a potato growing area within a bed system rather than in traditional ridges. The bed surface profile was formed to encourage water movement into the growing area, rather than runoff into the compacted traffic support area in the furrows. The differences in percentage runoff between the bed and ridge treatments is shown in fig 5.

The yield penalties in irrigated areas for allowing soil salinity levels to increase are well established (fig 6). Similarly, the consequences of soil structural deterioration through increases in exchangeable sodium, are similar to those resulting from compaction. Reclamation costs for alleviating sodium problems are extremely high, compared with the costs of preventative measures.

Larger scale soil conservation measures rarely eliminate soil loss and are often not feasible in small-holder agriculture. Preventative management through significantly reducing soil loss, can maintain soil fertility and hence production capacity.

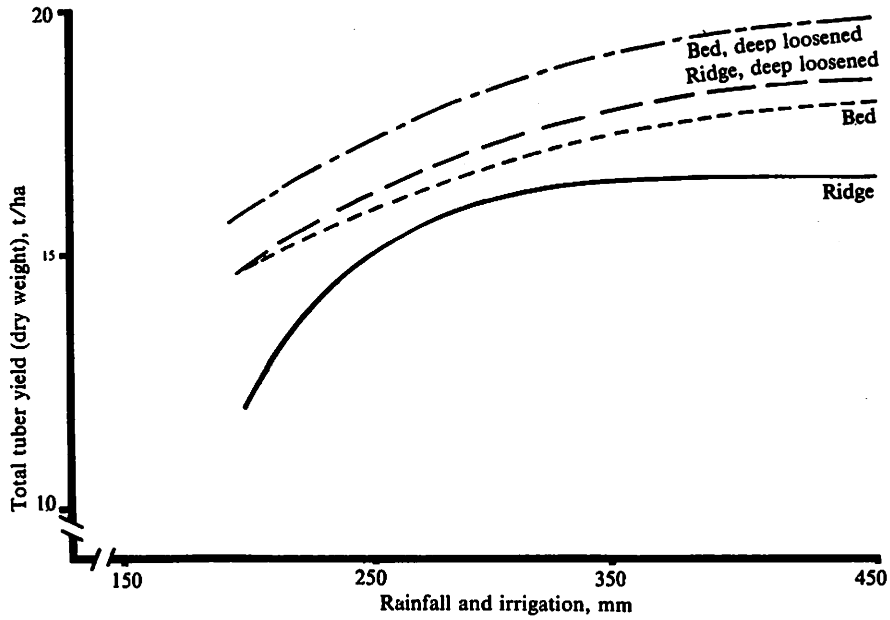


Fig 4 Influence of bed and ridge cultivation on potato yields (After Prestt 1983)

These potential benefits, coupled with the increasing difficulty and cost of satisfactory deeper soil reclamation do, I believe, force use into the situation where much more effort must be put into preventative rather than reclamation soil management.

5 Implications of moving towards a preventative management approach

In the tillage mechanisation area, preventative management must involve a reduction in the damaging effects of traffic, the modification of husbandry techniques and greater attention to subsurface drainage. Similarly, drainage and husbandry methods must be given greater emphasis in irrigated and erosion prone areas. Interest is increasing in the possibilities of preventative management, but doubts exist as to its feasibility. Possible ways forward, with suggestions as to where effort needs to be concentrated will be considered under the following categories:

a) reducing soil compaction potential of traffic;

Fig 5 Influence of bed and ridge cultivation on rainfall runoff

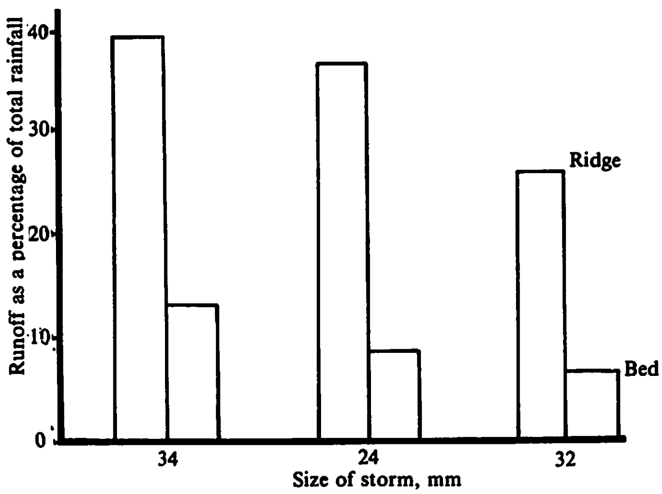
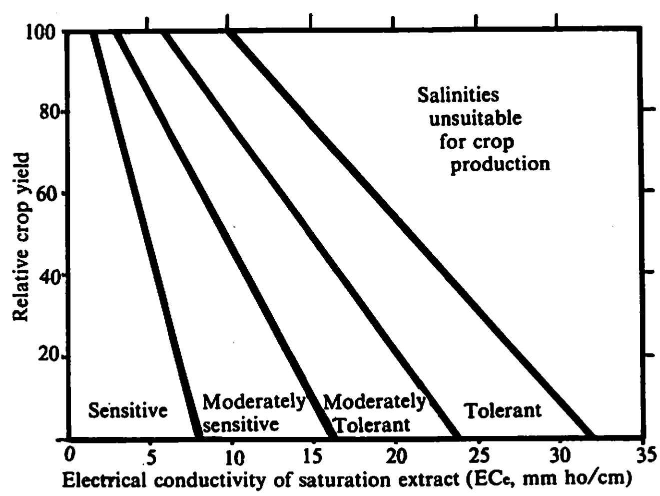


Fig 6 Relative crop yield as a function of the salinity of the soil saturation extract



b) field control of wheels and tracks;
c) soil preparation;
d) drainage;
e) cropping.

The two major factors influencing the compaction potential of traffic are the contact pressures and loads. Whilst it may be unrealistic to expect significant weight reductions in future, unnecessary weight can be shed and consideration given to restricting the magnitude of future increases. The suggestion made by Hakansson (1979) that axle loads of agricultural vehicles should be restricted to keep compaction damage within the top 400mm must be considered very seriously. Any move towards this goal or its actual achievement will require action with regard to contact pressures and wheel arrangements.

The levels to which farmers can reduce inflation pressures with current equipment and tyres is limited. Very low ground pressures (5 - 10 kPa) can be achieved on light, low traction vehicles using existing tyres. This is not possible however, with the current very high pressure equipment such as trailers, combines and other harvesters, nor on vehicles with high traction requirements. The use of dual wheels can help, but their application is frequently limited by width restrictions and maximum allowable bending moment and torque levels in existing axles. Many of these problems can be resolved at acceptable cost at the design stage, hence the need for the farmer to encourage manufacturers action to minimise the compaction potential of their products. Tremendous scope exists for the development of new wheel or track systems allowing good mobility whilst keeping axle loads and contact pressures within acceptable limits on high gross weight equipment. The use of power take-off power for either direct or indirect thrust to minimise weight and the multiple use of wheel or track type support equipment for traction, flotation and tillage are both fruitful areas for future development. Crop transport operations are frequently the most punishing to the soil and the continuing development of inter-linked field and road container systems offer much promise for the future. In the meantime, farmers can benefit from making best use of the tyre equipment available, ensuring operation of their current units at maximum allowable tyre deflections and by achieving adequate traction through minimum rather than maximum added weight.

Tramline and bed systems for the control of through crop traffic after establishment and before harvest have proved very successful. Their full potential for complete traffic control through all operations has still yet to be realised in most situations. To achieve this, further action is required on the matching of implement working widths, improving directional and lateral stability of tractors and implements and reducing rutting and erosion problems. The use of tramlines for transport operations at harvest is by no means fully exploited nor is the use of special sacrificial haulroads within a field, where it is not possible to leave large capacity trailers on headlands. Manufacturers have been able to assist considerably in supplying implements for use in tramline or bed situations for combine harvested crops, but much still remains to be done in the root crop area. Whilst gantry and winch systems are well worthy of further study, developments in permanent tramline or bed systems still offer greatest scope for the future.

Situations requiring soil disturbance may be significantly reduced in future if good traffic control can be established. Where soil disturbance is still necessary, however, there are two major information gaps constraining the future development of soil preparation techniques. These are lack of information on the actual soil environment required and of objective tests to define the soil environment. These aspects were less important in the past when almost complete reliance was placed on the successful combined action of mouldboard ploughing and weathering to provide the required soil conditions. Future research programmes need to be directed towards providing this information in a form which would enable a more precise approach to be taken to tillage in the field. This requires a clear definition of the necessary environments for the seed, roots and soil and water conservation so that appropriate conditions can be produced between the controlled traffic zones.

In field experiments in this area, it is important to remember the crop responds to its environment rather than to the tillage implement used and that it is often particularly sensitive to the timing of establishment. The implications of this are that different implements and techniques may have to be used on different sites and in different years to produce the same soil environment. In addition, provision needs to be made to enable the crop on each plot to be established when conditions allow, rather than waiting until the worst plot is ready and then seeding all plots together.

There has never been any shortage of inventive ideas and new machines in the tillage field. The main problem has always been that of objectively assessing their performance. A definition of the soil environmental requirements and the development of objective tests will enable better selection and use of the implements and provide more specific requirements to designers for new implements.

In the immediate future in situations where traffic control cannot be achieved, a reversal in the sequence of tillage operations should be considered so that soil loosening if required, becomes one of the last operations rather than the first, to minimise the risk of excessive re-compaction. Great scope exists for the better use and selection of tillage equipment to avoid the creation of new problems when overcoming the original one. There is similar scope for maximising the use of undisturbed soil strips during multi-pass operations, to maximise traction and minimise rolling resistance and compaction.

The long term maintenance and improvement of soil structure is mainly dependent on root and organism activity together with natural weathering action. This improvement can be best achieved through minimum soil disturbance by cultivations and surface traffic, and good subsurface drainage below. Subsurface drainage is therefore one of the most effective and necessary aids to preventative soil management, contributing by increasing the soil resistance to compaction as well as through improved aeration and salinity control. Drainage problems are most severe and solutions most expensive in the finer textured soils where close drain spacings are required. Appropriate soil loosening measures and mole drainage have much to offer in these situations and possibilities should be explored for widening the use of these techniques in conjunction with other subsurface systems. The most common drainage solution adopted in saline or potentially saline irrigated areas is one of relatively deep drainage. This practice can be extremely expensive and time consuming in areas of minimal slope and unstable soil conditions. With further development, trenchless pipe laying at closer spacings and shallower depths could be a very worthwhile alternative in many of these situations.

Soil erosion on erodible soils can only be prevented by protecting the surface soil layers and through maximising infiltration rates and minimising runoff. Much more attention needs to be paid to the field conditions if soil losses are to be avoided or reduced in many areas. Field conditions more resistant to soil loss can be achieved through appropriate crop selection and zero or precision tillage coupled where possible with the use of herbicides. Trends in recent years have been both towards reducing the number of farm enterprises and increasing farm size, with the demise of the crop rotation. In many situations farm size has now reached a point where more enterprises and crops could be contemplated and investigations into the possibilities of a return to the preventative management rotational system would be well justified.

To summarise, the major research and development role for the farmer in any move towards preventative management lies in the areas of field operation organisation and husbandry. The manufacturers part is in providing equipment of appropriate width and performance to match the field systems and to reduce the compaction potential of their equipment. The major priority for the research and extension worker is the definition of soil environmental requirements and the development of objective tests, as well as the promotion of field drainage and preventative husbandry measures.

6 Conclusions

Changes in mechanisation and soil handling practices in recent years have placed increasing pressure on the soil environment with soil structural problems tending to become more severe and deep seated. The previous approaches to soil management, based primarily on reclamation methods are rapidly becoming inappropriate, hence the need for a change towards more preventative management. Major benefits can be gained from following a preventative management approach, but they will only be attainable following a combined coordinated attack on the outstanding problems by farmers, manufacturers and researchers together. The slogan for the future must be "prevention is better than cure".

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The Institution of Agricultural Engineers
1984 Annual Conference and Luncheon
Wednesday, 9 May 1984, The National Agricultural Centre, Stoneleigh, Warwickshire

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"AGRICULTURAL ENGINEERING TOWARDS 2000"

(A view from the manufacturing industry)

Aims:

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To examine some of the major factors which are likely to influence developments in the agricultural engineering and allied industries over the next 15 years.

To consider the nature of these developments in terms of products, markets, performance and structure of the industry.

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Background:

A Government Department, a learned society and a university have each studied and published reports on the British agricultural engineering manufacturing industry.

The Institution of Agricultural Engineers is devoting its 1984 Annual Conference to giving representatives of the manufacturing industry the opportunity of presenting views about future developments in, and prospects for, the industry.

The Conference will form part of a 2-year series of activity initiated by the Institution, intended to take stock of the agricultural engineering industry and profession as it prepares for entry into the 21st Century.

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Programme:

10.00 - 10.30	Coffee		
10.30 - 10.50	Conference will be opened by the President		
10.50 - 11.10	Paper 1	The Group concept	John Young
11.10 - 11.20	Discussion		
11.20 - 11.40	Paper 2	Prospects for the smaller company	Geoffrey Evans
11.40 - 11.50	Discussion		
11.50 - 12.10	Paper 3	Starting a new company	David Elder
12.10 - 12.20	Discussion		
12.20 - 15.00	Lunch		
15.00 - 15.20	Paper 4	A European view	Michael Bealing
15.20 - 15.30	Discussion		
15.30 - 16.00	FORUM		
16.00	Tea and disperse		

Registrations & Enquiries:
Conferences Section
The Institution of Agricultural Engineers
West End Road
Silsoe, Bedford MK45 4DU

Telephone: Silsoe (0525) 61096

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The Principal Guest will be John Butcher MP, Parliamentary Under Secretary of State for Industry

An examination of the feasibility of roofless accommodation for rearing fattening cattle during the winter in North East Scotland

C D Mitchell and P J Broadbent

Abstract

THE effect of two environments on the health and performance of British Friesian male castrates were compared in each of two experiments. The two environments were (a) a naturally-ventilated roofed unit with slatted floors and (b) a roofless unit with walls to provide wind protection. The roofless unit was fitted with a single-slot floor in Experiment 1 (1975/76 winter) and slatted floors in Experiment 2 (1976/77 winter). Within each environment the animals were penned in groups and individually fed.

The additional capital and running costs associated with the roofed accommodation did not appear to be justified in terms of animal health and performance when compared to the roofless accommodation.

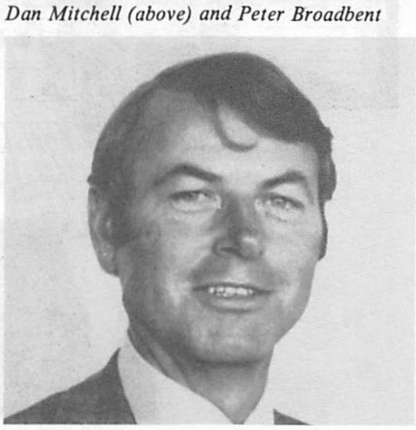
Introduction

Conventional roofed cattle buildings have a high capital cost per animal housed. Detailed design studies and costings showed that roofless accommodation with a single-slot floor had the potential to provide confinement at the lowest capital cost per animal place. The next cheapest design was a roofless-slatted unit and both, fully costed for construction by contractors, had a lower capital cost per animal place than roofless cubicles (Mitchell 1974).

The single-slot floor was originally developed in America (Magson 1974; Moore *et al* 1974).

Detailed costings using contractors prices (Wight 1974) of roofless-slatted accommodation for cattle indicated that omission of the roof and the concomitant supporting structure would reduce capital costs by 25–30%. Omission of the roof and supporting structure simplifies construction and units on commercial farms have been erected mainly by farm labour.

Dan Mitchell (above) and Peter Broadbent



Dan Mitchell, who is now with the Electricity Council, Farm Electric Centre, National Agricultural Centre, Stoneleigh, Kenilworth, Warwickshire, carried out this investigation when he was at the Scottish Farm Buildings Investigation Unit, Craibstone, Bucksburn, Aberdeen. Peter Broadbent is in the Animal Husbandry Department at the North of Scotland College of Agriculture, 581 King Street, Aberdeen.

Refereed paper: manuscript received 21 April 1983 and accepted in revised form 23 September 1983.

The most common form of roofless cattle accommodation prior to the development of the roofless-slatted unit was the roofless cubicle unit. Roofless-slatted units have a number of advantages over roofless cubicles. These include:—

a) lower capital costs;
b) no requirement for bedding, or labour to bed cattle;
c) no requirement for scraping in the passageways, thus saving labour and equipment;
d) slurry storage incorporated in the unit, whereas roofless cubicles require separate slurry storage;
e) a reduction in total area required;
f) a lower requirement for rainfall storage, due to the reduced total area.

Work by Webster (1970), McQuitty, Rutledge and Howes (1972), and McCarrick and Drennan (1972) indicated that it might be feasible to use roofless housing for winter rearing of cattle in the North East of Scotland. The critical temperatures of cattle housed in a roofless unit were calculated for different combinations of climatic conditions based on average feed intakes (Bruce 1975). These calculations supported the feasibility of roofless housing but indicated that a 70% reduction in wind speed at animal level was required during the winter months.

An experimental structure incorporating wind protection and a single-slot floor was erected in 1975 to house 30 finishing cattle in three pens of 10. The degree and type of wind protection was based on model studies (Ross 1975). Single-slot floors are designed so that cattle tread the excreta down a slope to a 50 mm slot above a 300 mm pipe. The excreta are then flushed from the pipe to storage in a lagoon outside the building thereby making single-slot units similar to roofless cubicles in this respect. Single-slot floors have been used successfully in America in units where cattle were fed maize or maize silage diets. They had not been tested using low dry matter diets such as those based on grass silage or roots.

The diets fed to cattle in the experimental structure were based on grass silage and because the cattle became very dirty on the single-slot floor, it was removed and replaced by slats in the summer of 1976.

Since rate of eating is influenced by dietary dry matter and energy contents, and both rate and duration of intake might be influenced by climate, a range of diets was used to enable animal performance in a roofless unit to be evaluated with diets differing in dry matter and energy contents.

Materials and methods

Experiment 1

The objective of this experiment was to examine the performance of cattle in a single-slot unit (roofless) (fig 1) and to compare their performance with that of cattle in a slatted unit (roofed) (fig 2). Three diets were used in the roofless unit, two of which were used in the roofed unit, to assess whether environment × diet interactions occurred.

Forty-six British Friesian male castrates were used, thirty in a single-slot unit (roofless) and sixteen in a slatted unit (roofed). The cattle in both units were penned in groups and individually fed using Calan-Broadbent electronic doors (Broadbent *et al* 1970) and they were all weighed weekly. The thirty cattle in the roofless unit were formed into three groups of ten consisting of the heaviest, lightest and intermediate weight cattle. The groups were allocated to pens at random and the cattle within groups were allocated to diets and feed positions at random. The animals in the roofed unit formed part of a larger experiment and were also allocated at random to pens, diets and feed positions. The experiment started in November 1975, following an introductory period of three weeks, and lasted 15 weeks.

Blood samples were taken from animals in the roofless unit and a series of biochemical and haematological determinations were carried out on these blood samples to establish whether the cattle were normal in this respect.

The roofed cattle were housed on 125 mm slats with 37 mm gaps in pens 3 m deep with 1.86 m^2 per animal. The roofless unit had three pens with the same type of floor in each pen. In the centre of the 3 m deep pens was one 50 mm slot parallel to the feed trough. The pens allowed 1.86 m^2 per animal and the solid concrete area sloped 1:16 and 1:12 towards the slot.

Three diets were fed in each pen of the roofless accommodation. The diets were two ratios of silage: barley dry matter 80:20 (A) and 60:40 (B) and a 72:28 mixture of barley and wet distillers grains (C) on a dry matter basis. The estimated metabolizable energy contents of the diets were 10.3, 11.2 and 12.8 MJ/kg DM, respectively. The average dry matter values from weekly samples for the barley, draff and silage were 773, 296 and 221 g/kg, respectively. In the roofed-slatted unit, eight animals were on diet A and eight on diet B.

Experiment 2

The objective of this experiment was to examine the performance and cleanliness of cattle in a roofless-slatted unit (fig 1) and compare their performance with that of cattle in a roofed-slatted unit (fig 2). Thirty-eight British Friesian male castrates were used, thirty in the slatted unit (roofless) and eight in the slatted unit (roofed). The cattle in both types of accommodation were penned in groups and individually fed. They were all weighed weekly.

The thirty cattle in the roofless accommodation were ranked in order of live weight, and allocated at random to pens, diets and feed positions. The animals in the roofed accommodation formed part of a larger experiment (Petchey and Broadbent 1980). The experiment started in November, 1976, following an introductory period of three weeks to pens, diets and feed positions, and, lasted 15 weeks. The two diets were 80:20 (A) and 60:40 (B) silage:barley on a dry matter basis. The average dry matter values from weekly samples for the barley and silage were 815 and 211 g/kg, respectively.

In the roofed accommodation four animals were on the 60:40 ratio and four on the 80:20 ratio. All the animals were fed to appetite. The indoor cattle (pen 4) were housed on 125 mm slats with 37 mm gaps as in experiment 1. The roofless accommodation consisted of three pens each with different floors:

pen 1 125 mm slats;
pen 2 300 mm slats;
pen 3 600 mm slats with a slope of 1 in 12 from the centre to the outer edge.

In each case, the gap between the slats was 37 mm and the different floors outside gave void ratios of 9, 4 and 2 times that of the original single-slot floor. The floors in the roofless unit were finished with a timber batten in experiment 1 and the slats in experiment 2 with a wire comb to give non-slip surfaces. The mean skid

Fig 1 Roofless slatted unit: A honeycombed pen walls; B slurry storage; C slatted pens; D Calan – Broadbent

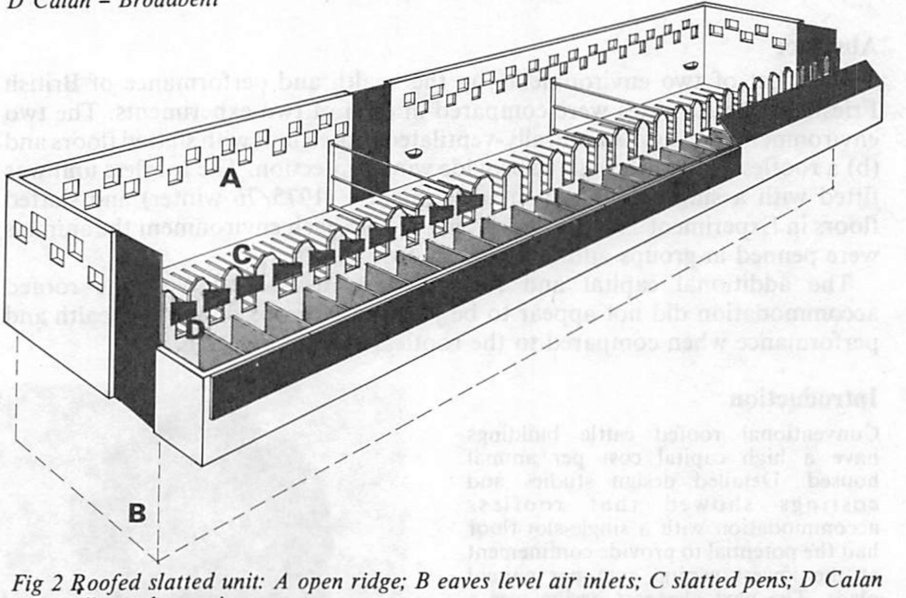
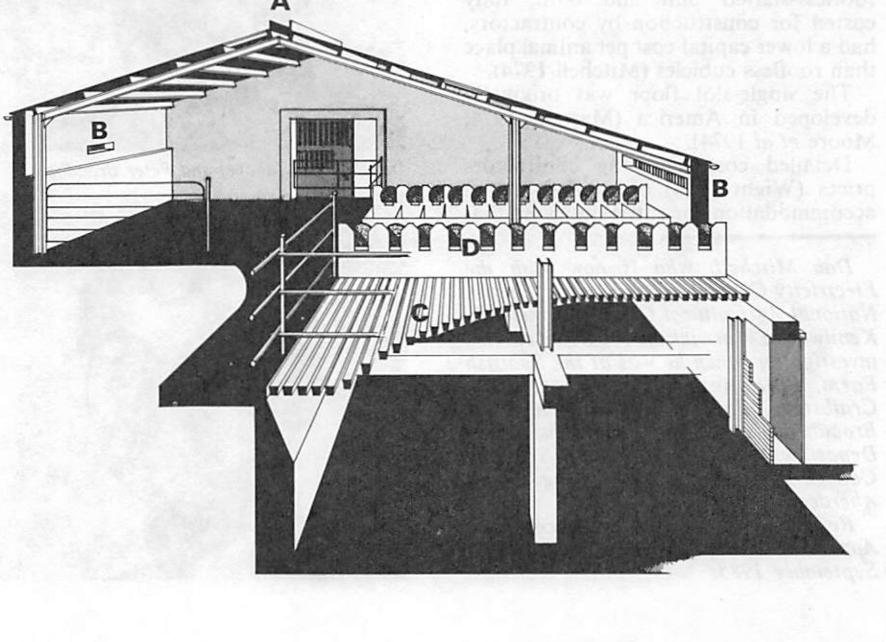


Fig 2 Roofed slatted unit: A open ridge; B eaves level air inlets; C slatted pens; D Calan – Broadbent electronic gates



resistance (Road Research Laboratory 1969) and coefficient of static friction measurements were similar for both floors. The skid resistance value was 94.4 and the coefficient of static friction between a steel plate and the floor 0.72. The smooth slats in the roofed unit had values of 34.0 and 0.61, respectively.

The stocking density in both types of accommodation was 1.86 m²/animal and the pens were the same as used in experiment 1. Blood samples were taken from the outside animals and a series of biochemical- and haematological determinations were carried out on these samples. The extent of hypocupraemia, cobalt pine, anaemia and selenium status and the level of ostertagiasis infection were assessed. Behavioural studies of cattle in the roofless accommodation were carried out over two twenty-four hour periods because visitors observed that the cattle outside were only seen standing. The following activities were recorded at one minute intervals (Robertson, *et al* 1977):

a) number of animals standing
   i) feeding
   ii) not feeding;
b) number of animals lying.

The climatic information for experiment 2 is summarised in table 1. The data was analysed using a technique for samples of unequal size. The results are discussed separately for each diet in each year.

Results

Experiment 1

One animal on diet C became severely bloated and was removed from the experiment. Another animal on diet C which experienced eye troubles and a series of fits was slaughtered. Cerebral cortical necrosis was diagnosed on post-mortem examination. These two animals were treated as missing plots and these values fitted by standard techniques in the analysis of variance.

The results of experiment 1 are given in table 2. The results of the biochemical and haematological tests are presented in table 3.

There were no significant differences between the two groups of cattle on diet A in terms of initial live-weight, final live-weight, daily live-weight gain, ME intake or feed conversion efficiency. The variability of live-weight gain was lower for cattle housed outside (roofless) than those inside (roofed).

The cattle on diet B (roofed) performed better than those in the roofless accommodation. There were no significant differences between the two groups in initial and final live weights but the difference in daily live-weight gain was significant ($P \leqslant 0.001$). The total ME intake for cattle in the roofed accommodation was 4% greater than that for cattle in the roofless accommodation

Table 1 Climatic conditions Aberdeen (Dyce)

	30 year average			*Winter 1976/77*		
	Sun, h	*Rain, mm*	*Temperature, °C*	*Sun, h*	*Rain, mm*	*Temperature, °C*
1976						
September	119.0	67	11.7	73.9	173.5	11.7
October	94.2	80	9.1	73.7	179.7	9.3
November	58.3	86	5.3	88.7	45.2	4.7
December	46.0	76	3.3	54.6	142.7	1.1
1977						
January	51.1	79	2.3	46.2	70.3	2.0
February	79.5	56	2.6	64.5	118.2	2.3
March	106.5	50	4.4	90.3	52.0	5.3
April	153.2	47	6.6	164.5	50.5	5.9
May	171.6	68	8.9	203.0	87.5	8.7
Totals for October to April (inclusive)	588.8	474	–	582.5	658.6	–
Average	–	–	4.8	–	–	4.37

Table 2 Performance data for cattle in roofless and roofed cattle accommodation, winter 1975/76

	Performance for diet and housing treatments			*SE of treatment differences 37 d f*		*Levels of† significance*
	A + B Roofless	*A + B Roofed*	*C Roofless*	Smallest	Largest	
Number of animals	20	16	8			
Initial weight, kg	384.2	381.0	385.7	10.2	11.4	N.S.
Final weight, kg	470.6	483.6	463.7	12.6	14.0	*
Daily live-weight gain, kg	0.82	0.97	0.73	0.07	0.08	***
Energy intake, MJ (ME)/day	93	95	87	5.0	5.6	**
Energy conversion ratio, MJ (ME)/kg gain	115	100	121	7.0	7.8	*

Diets A 10.3 MJ/kg 80:20 (on a dry-matter basis) silage: barley
B 11.2 MJ/kg 60:40 (on a dry-matter basis) silage: barley
C 12.8 MJ/kg 72:28 (on a dry-matter basis) barley: draff (50:50 percentage composition)

† *In this and subsequent tables, the levels of significance are indicated as NS = non-significant,* * = $P<0.05$, ** = $P<0.01$, *** = $P<0.001$.

Table 3 Mean and S D values for blood samples taken during experiments 1 and 2

Date	*Number of animals*	*Haemoglobin, g/100 ml*		*P C V, %*		*Copper, µg/100 ml*		*Pepsinogen, µg/litre*		*Vit B12, mg/litre*		*GSH-PX, µg/ml cells*	
6/11/75	30	12.0	(1.2)	35.2	(4.4)	73.2	(23.0)	0.72	(0.21)	203	(57)		
6/5/76	30	13.5	(1.1)	36.5	(3.0)	80.3	(10.5)	0.81	(0.37)	456	(106)		
20/12/76	10	12.1	(1.5)	34.7	(3.8)	71.4	(19.6)	0.54	(0.17)	238	(87)	7.29	(2.18)
31/1/77	20	10.7	(1.1)	35.8	(3.2)	74.6	(7.4)	0.60	(0.22)	265	(61)	9.02	(7.22)
31/3/77	30	13.5	(1.2)	36.7	(3.1)	73.1	(9.8)	0.74	(0.18)	367	(104)	12.62	(4.8)
Population mean†		13.8	(± 1.4)	35.3	(± 3.2)	81.0	(± 20.1)	0.84	(± 0.31)	320	(± 96)	8.65	(± 4.6)

† *Population mean for cattle in the North East of Scotland (G J Halliday 1976)*

due to difficulties experienced in feeding the cattle in the roofless accommodation to appetite. The difference in feed conversion efficiency was not significant.

Experiment 2

The results of experiment 2 are shown in table 4. The results from the blood sampling are shown in table 3.

The cattle in the roofed accommodation had higher initial and final live-weights than the cattle in the roofless accommodation but the differences were not significant. This was checked to see if the starting conditions were sound.

Differences between groups roofed and roofless on diet A with regard to daily live-weight gain were small and not significant. There were significant differences ($P \leqslant 0.05$) between roofed and roofless on diet B with inside greater than pen 2 (300 mm slats). The differences between roofed and roofless pens 1 (125 mm slats) and 3 (600 mm slats) on diet B were not significant but gains were greater in the roofed accommodation than in both pen 1 and pen 3 (roofless).

Animals in pens 1 and 2 were markedly cleaner than those in pen 3. Differences in daily metabolizable energy (ME) intake were significant ($P \leqslant 0.05$) between pen 3 and both roofed and pen 2, with pen 3 intake > roofed > pen 2. This suggests that the standard of cleanliness achieved did not detrimentally affect total feed intake over the winter period.

In experiment 2, food intake was not restricted by problems of feeding to appetite and this is demonstrated by the daily ME intakes shown in table 3. Intakes in most pens, eg pens 1, 2 and 3 on diet A and 1 and 3 on diet B, exceeded the corresponding intakes for the same diets inside (roofed).

Differences in feed conversion ratio between pens outside and between inside and outside on both diet A and B were small and non-significant.

In each case, animals on diet B performed better than those on diet A. Feed conversion ratio outside was slightly better than inside on diet A and slightly worse than inside on diet B. The blood values obtained from cattle in the roofless accommodation were compared in table 4 with a population mean for normal beef cattle in the North East of Scotland (Halliday 1970). Performance was not impaired by anaemia, hypocupraemia, ostertagiasis, cobalt pine or selenium deficiency.

Skin temperatures recorded at the rump, flank and shoulder on cattle outside are given in table 5. They indicate that the animals were above their critical temperatures during daylight hours. The average temperature for the three skin sites ranged from 28.1 to 29.9°C over a range of environmental conditions. Multiplying these figures by 0.9 gives values corresponding to average skin temperature for the whole animal (Webster 1976). The tissue insulation of these animals at their critical temperature would be about 0.26°C m^2W^{-1} and they would be vaso-constricted. Skin temperatures ranging from 28.1 to 29.9°C, corrected to average skin temperature for the whole animal, give tissue insulations of 0.09 to 0.08°C m^2 W^{-1}, so the animals were not vaso-constricted and, therefore, were well above their critical temperatures.

Discussion

It is difficult to form firm conclusions and extrapolate from the results of these experiments because the housing treatments were essentially unreplicated and were only tested over two minutes in one location. The consequence of this is that the errors for any comparison involving housing effects may be under-estimated. However, this is a problem faced by many experiments involving environmental factors and the results may be judged in relation to those obtained in similar studies.

In experiment 1, there were difficulties in feeding cattle outside to appetite due to bolts freezing on the Calan/Broadbent doors and difficulties with water intake due to the water supply freezing. The feed intake data showed greater variability outside than inside and, on a number of occasions, there were no residues outside, indicating that intake had been previously restricted. The data for this experiment should be considered in relation to these problems. In a commercial situation, variations in intake with change of climate would be catered for by adjusting the quantity of food offered.

The dirtiness of the cattle in the single-slot unit (experiment 1) was due primarily to the diets fed. A drier diet would have produced cleaner conditions but would have restricted the commercial use of the single-slot concept by making it diet specific.

Early reports on single-slot floors, (Magson 1974), did not mention the diet fed in America or indicate that the

Table 4 Performance date for cattle in roofless and roofed slatted accommodation, winter 1976/77

	Cattle performance for various treatments									
Housing	*Roofless*			*Roofed*	*Roofless*			*Roofed*	*SE of*	*Level of*
Diet	*A*			*A*	*B*			*B*	*difference*	*significance*
Number of animals	5			4	5			4	*30 d f*	
Pen number	1	2	3	4	1	2	3	4		
Slat size, mm	125	300	600	125	125	300	600	125		
Initial live-weight, kg	347.0	341.0	347.0	364.5	348.4	339.0	340.0	374.8	7.8	N S
Final live-weight, kg	423.0	422.0	428.0	435.0	463.0	439.0	448.4	492.8	10.7	N S
Daily live-weight gain, kg	0.72	0.77	0.77	0.67	1.09	0.95	1.03	1.12	0.06	*
Daily ME intake, MJ	73.3	73.3	78.3	70.8	94.7	87.7	94.0	92.3	2.74	*
Feed conversion ratio, MJ/kg daily live-weight gain	103.5	95.9	104.1	106.6	91.1	93.5	91.3	83.8	4.8	N S

Diets A *10.3 MJ/kg D.M. 80:20 (on a dry-matter basis) silage:barley*
B *11.2 MJ/kg D.M. 60:40 (on a dry-matter basis) silage: barley*

Table 5 Skin temperatures † for cattle confined in roofless accommodation in the winter 1976/77

Date	*Number of animals*	*Average weight, kg and (S D)*		*Mean skin temperatures, °C and (S D) during daylight hours*						*Air temperature °C*	*Net radiation W/m²*	*Cloud cover*	*Rainfall*	*Wind speed, km/h*
				Rump		*Flank*		*Shoulder*						
16/12/76	10	368.4	(10.2)	28.7	(0.31)	28.6	(0.31)	28.3	(0.34)	2	15	Full	Light drizzle	0
24/1/77	10	396.4	(9.6)	29.9	(0.35)	29.5	(0.27)	30.2	(0.33)	5	50	None	Dry	8
7/2/77	10	411.3	(11.1)	28.3	(0.33)	28.2	(0.36)	27.9	(0.31)	3	35	Full	Damp coats	3
23/2/77	10	419.4	(10.7)	28.8	(0.25)	28.8	(0.20)	28.6	(0.34)	3	190	None	Dry	10
7/3/77	10	424.6	(10.8)	29.6	(0.34)	30.3	(0.33)	29.5	(0.22)	8.5	180	None	Dry	10
7/3/77	10	42.6	(10.8)	29.5	(0.34)	28.8	(0.51)	29.1	(0.23)	9	200	None	Dry	30

† *Measurements were taken outside the roofless unit away from wind protection*

concept might be diet specific. Later reports, eg Kirsh (1976), suggested that the use of the single-slot floor was declining in America due to dirtiness, insect and odour problems.

Experimental results for cattle of a similar genotype fed a diet similar to diet C in experiment 1 and housed in the slatted court at Craibstone were published by Broadbent *et al* (1971, 1976). In this work, cattle gained 0.90 kg/day when fed *ad libitum* over the growth range from 300 to 400 kg. The cattle in the roofless single-slot unit gained 0.73 kg/day from 385 to 463 kg on a similar diet, but intake was thought not to be *ad libitum*.

The bloating problems experienced in this work were not reported by Broadbent *et al* (1971, 1976) whose cattle were younger and lighter when introduced to the diet. These problems may have been due to feeding the diet to older, heavier cattle or to the wetting of the diet during periods of rain or snow.

In experiment 2, the problems of feeding to appetite outside were overcome by offering extra food outside to cater for the greater variability of intake experienced in experiment 1 and by applying low temperature grease to the bolts on the Callan/Broadbent doors to prevent freezing. Electric pipe trace heating was added to the water system and prevented freezing.

The slatted floors in the roofless accommodation produced a marked improvement in animal cleanliness compared to that on the single-slot floor. Cleanliness in pens with 125 and 300 mm slats was similar to that in the roofed-slatted court. On the 600 mm wide slats cleanliness was better than on single-slot floors but marginal with regard to acceptability if cattle were to be sold for slaughter from such a unit. The slope from the centre to the edge of the 600 mm slats on this floor made it similar in design to a single-slotted floor with single-slots at 600 mm intervals.

The behavioural studies showed that the behaviour of the cattle observed was similar to housed cattle kept indoors in a loose housing system (Robertson *et al* 1977). The time spent lying ranged from 49.3 to 54.4% of the 24 hour period over the two observation days and three pens. The time spent standing was 36.0 to 40.4%. The time spent feeding was 9.7 to 12.2%.

There was a notable absence of respiratory problems outside and an absence of foot and leg injuries.

The exact climatic limitations to the use of roofless-slatted accommodation are not yet known. On the basis of initial studies, it appears that heavy rainfall can reduce food intake but, in the Aberdeen area, cattle find it possible to compensate for this reduction. Heavy rainfall over long periods might depress intakes to a marked degree. There would also be a need to collect and store excess rainfall in areas where precipitation markedly exceeded evaporation during the winter months. In these circumstances, it might well be that the cost savings from foregoing the roof would be outweighed by extra storage costs for effluent.

The overall results of the two experiments support the feasibility of roofless accommodation with wind protection for winter cattle housing in lowland areas of North East Scotland. A number of roofless-slatted units were built on commercial farms in parallel with this work and have been operated successfully (Mitchell and Gaisford 1977).

Farmers who built roofless-slatted units in parallel with this work were motivated by the potential savings on capital costs but their experiences in operating these units have led them to emphasise the positive benefits to the general health and hardiness of cattle as important factors contributing to the choice of such accommodation.

Acknowledgments

We acknowledge the provision of facilities by the Governors and Principal of the North of Scotland College of Agriculture and the advice and assistance provided by our colleagues and technical staff. The computer programming was carried out by Mr J J Clark, Scottish Farm Buildings Investigation Unit, statistical assistance was given by Mr E A Hunter, Agricultural Research Council Unit of Statistics, Edinburgh, the drawings were produced by Mr J Wiseman and blood sampling was undertaken by Mr G J Halliday, Veterinary Investigation Service, North of Scotland College of Agriculture.

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Soil penetration by disc coulters of direct drills

A G Gray, D MacIntyre

Summary

THIS paper represents preliminary work undertaken for the design of a new type of direct drill.

A survey was carried out to measure the weights, forces applied and diameters affecting the soil penetration of disc coulters on five commercial direct drills and one conventional drill. This was followed by an investigation to assess disc coulter design factors which affected the degree of soil penetration achieved. The work was carried out in a soil tank containing a loam of the Hobkirk series.

The results indicated that factors such as forward speed and disc diameter, when increased, had a negative relationship with depth of penetration. Disc sharpness had a positive effect on coulter depth achieved.

Introduction

Approximately 2.7% and 0.5% of cereal crops in England and Scotland respectively are now sown with direct drills (Holmes and Gray 1979). The placement of seed in uncultivated land requires a different technique from that associated with conventional seed drills. This is achieved in varying ways by the commercial machines available and an investigation was therefore undertaken to examine the methods employed. The main features in the construction of direct drill coulters were noted and, so far as was practicable, the maximum force that could be applied by each coulter on to the soil surface to obtain penetration, was measured.

Several parameters affect the degree of soil penetration of disc coulters, namely, the diameter of the disc, the forward speed, the degree of soil compaction, the downward force applied and disc sharpness (Culpin 1976). The above parameters were investigated under controlled conditions in a soil tank in order to relate the forces on disc coulters of commercial drills to disc penetration of the soil.

Commercial drill survey and investigation

Description of machines

The following machines were investigated, detailed specifications being given in table 1.

Fernhurst

The Fernhurst drill is one of the original direct drill designs (Koronka 1973), many of its features being incorporated in present commercial machines.

The coulter consists of a triple disc system with a leading cutting disc and two rear angled discs, forming a 'V' shape to cut a slot in which the seed is sown.

The machine has a basic coulter load transfer mechanism whereby two double acting hydraulic rams lower the coulter drag arms to the ground. A hydraulic pressure gauge fitted into the system enables the operator to determine the pressure applied. Each coulter is individually sprung.

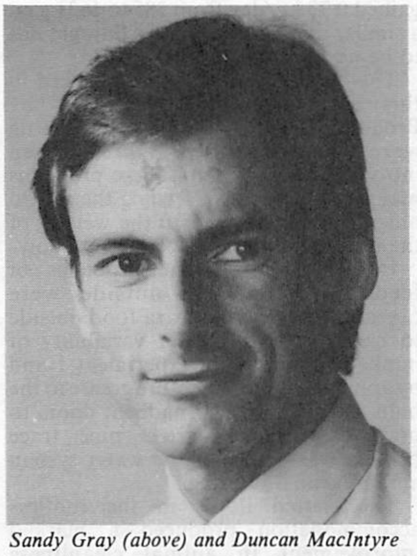
Moore Uni-drill

The Moore Uni-drill has the lowest weight of the direct drills investigated, although it has the greatest number of coulters because of its narrow row spacing.

Each drag arm supports two staggered coulter units, each comprising a disc and adjacent seed shoe, the latter constructed from rectangular hollow section. Each coulter unit arm is extended backwards to carry a cast iron ring to act as a press roll which runs immediately behind each drilled seed row. Two double-acting hydraulic rams, positioned at the side of the machine, raise and lower the coulter assembly. A depth control screw alters the pitch of the coulter drag arm assembly so that a major proportion of the drill weight can be transferred between the disc coulters and the press rolls. For example, to increase coulter penetration in hard conditions, most of the machine weight can be transferred to the discs by having the rollers off the ground.

Bettinson 3-D

The Bettinson 3-D drill has a triple disc coulter system similar to the Fernhurst. Two double acting hydraulic rams transfer the weight of the machine to rubber buffers (fig 1), mounted on each of the coulter assemblies, by raising the land wheels to increase the degree of penetration. Concrete blocks can be obtained to increase the weight of the machine and hence coulter penetration if required.



Sandy Gray (above) and Duncan MacIntyre

Hestair Bettinson DD

The Hestair Bettinson DD drill has the same coulter design features as the Bettinson 3-D. However, the hydraulic rams are attached to a coulter drag arm support beam which covers the width of the machine instead of being coupled to the wheels as in the Bettinson 3-D. There is no allowance for individual movement of the coulter drag arms, except for that provided by rubber buffers.

Massey Ferguson 130

The Massey Ferguson 130 drill has triple disc coulters with a leading disc cutting a slit and the remaining two discs forming a 'V' shape to cut a slot in which the seed is sown. Coulter penetration is controlled by two hydraulic double acting rams attached to a coulter drag arm support beam. The rams govern the penetration

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Refereed paper: manuscript received 22 June 1983 and accepted in revised form 20 September 1983.

Table 1 Machine specifications

Machine	Mean unladen weight per coulter, kg, (kN)	Dimensions of discs: Leading disc dia, mm	Dimensions of discs: Coulter disc dia, mm	No. of rows	Nominal row spacing, mm	Maximum unladen weight, kg	Sowing width, m
Fernhurst	238 (2.33)	250	250	15	160	3563	2.40
Moore Uni-drill	113.9 (1.12)	250	400	18	121	2050	2.17
Bettinson 3-D	139.7 (1.37)	200	350	15	178	2096	2.67
Hestair Bettinson DD	145.2 (1.42)	200	350	17	175	2469	2.98
Massey Ferguson 130	178.8 (1.75)	250	350	15	175	2682	2.63
Massey Ferguson 30	56.8 (0.56)	350	—	15	175	853	2.63

Table 2 Static test to show force (kN) on cutting edge of disc coulters

Coulter movement, mm	Force, kN: Fernhurst	Moore Uni-drill	Bettinson 3-D	Hestair Bettinson DD	Massey Ferguson 130	Massey Ferguson 30
10	0.32	0.73	0.80	NA	0.47	0.11
20	0.39	0.87	NA	NA	0.53	0.14
30	0.49	1.02	NA	NA	0.59	0.16
40	0.58	1.09	NA	NA	0.68	0.18
50	0.71	1.19	NA	NA	0.68	0.20
60	0.82	1.39	NA	NA	0.78	0.29
70	0.91	1.80	NA	NA	0.99	0.40
Max.	2.33	1.86*	1.37	1.42	1.44	0.40

Note: NA = Not applicable due to design of coulter movement restricting number of measurements taken. Nevertheless these drills provided similar sowing depths to those drills with recorded figures

** Due to the moments produced by the press rolls, the maximum force achieved in work with this machine was greater than the maximum unladen weight per coulter (table 1)*

of the discs by transferring the weight of the machine to the coulters via the support beam. The range of ram movement, and hence sowing depth, is controlled by the fitting or removal of spring caliper spacers around each hydraulic rod.

The Massey Ferguson 130 drill was the heaviest machine investigated. To improve disc penetration, the basic weight of the machine can be increased with water ballasted tyres (673 kg), wheel weights (190 kg) and concrete weights (234 kg) below the footplate.

Massey Ferguson 30
The Massey Ferguson 30 drill was included to provide a comparison between conventional and direct drills. The coulters of this drill are single discs with conventional seed boots. A centrally mounted single-acting hydraulic ram is linked to a coulter spring support beam; when extended the ram lowers the coulters to the ground, but the release of the ram allows the beam to return to its transport position by means of a spring.

Between each coulter arm and the support beam, there is a compression spring to resist vertical movement of the coulter and hence to improve penetration.

Test procedure for measuring force on drill coulters

The Scottish Institute of Agricultural

Fig 1 (left) Bettinson 3-D rubber buffers on coulter assembly

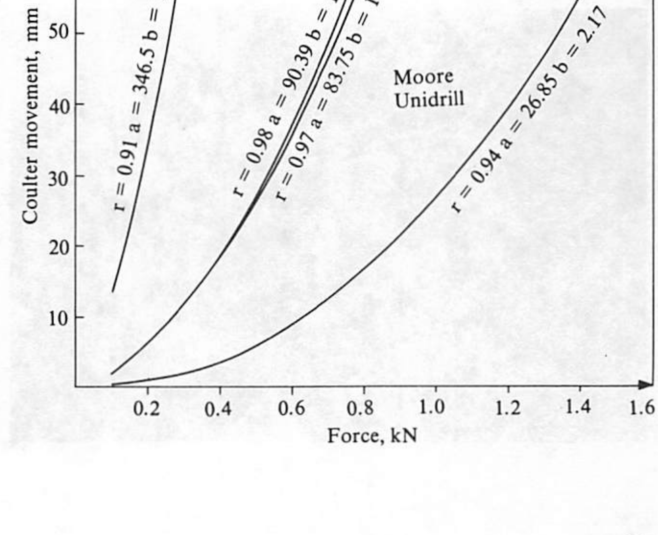


Fig 2 (right) Force/coulter movement relationship on leading discs of commercial machines

Engineering/West of Scotland Agricultural College weigh pads (Jamieson and Bartlett 1979) were used to determine the load on the cutting edge of the disc. A weigh pad was placed under a disc and then raised on a hydraulic jack until the disc and pad were just touching without a reading appearing on the digital meter. The jack was then raised in 7 steps, one centimetre at a time, readings being taken at each step. This procedure was undertaken three times with each coulter tested.

Results of test on commercial direct drills

The results of the force measurements obtainable on the cutting edge of the leading disc of the coulters are given in table 2 and fig 2.

Only maximum load could be recorded with the Hestair Bettinson DD machine due to the design of the coulter movement. For a similar reason only one additional intermediate reading was possible with the Bettinson 3-D drill.

The variation of force on the disc coulter can be related to the weight of the drill, the number of coulters and the mechanism for maintaining coulter penetration, the majority of manufacturers opting for a spring arrangement. The maximum force of penetration was obtained with the Fernhurst drill because the machine carried 2 lengths of railway line running across the width of the drill as ballast. The results indicated that, due to the moments provided by the press rolls, the greatest force at any given coulter depth (other than maximum) was given by the Moore Uni-drill, except for depths of 10 mm when the Bettinson 3D coulter provided the greatest force. The second highest forces were provided by the Massey Ferguson 130 and Fernhurst drills and from the limited work done with the Hestair Bettinson DD and the Bettinson 3-D drills, these could be ascribed to the same group. As expected only comparatively low coulter forces could be obtained with the conventional Massey Ferguson 30 drill.

At any one setting, the variation of force applied between coulters on the same make of machine was negligible.

Investigation of effects of disc coulter parameters on depth of penetration

Experimental treatment

The soil type used in the soil tank throughout the investigation was a red loam (USDA 1951) of Hobkirk series (Ragg and Futty 1967), as given in table 3, at initially two different compaction levels. These levels were prepared with the use of a mechanical vibrating roller (Bomag BW 75E) weighing approximately 0.5 tonnes, the lighter compaction being obtained with two passes of the roller unvibrated and the heavier with the same two passes plus two passes vibrated.

Each fill of the tank (measuring 15 m in length), representing one plot, was sub-divided into nine individual test runs. The downward force required on a disc coulter was measured for three disc sizes, at three depths, one forward speed (initially three forward speeds were used — see under results), over three replicates.

Large variations in 'r' values occurred after plotting coulter force and depth measurements from the light soil compaction (experiment 1). As it was difficult to obtain uniform compaction at low values, it was considered that variations in disc depth were the cause of the error, so trials recorded here were completed with the heavier compaction only (experiment 2).

Before beginning each run, the force required for the disc to penetrate to a certain target depth was gauged as accurately as possible with guide lines engraved on the side of the disc to give a visual indication throughout the run. After the tank had been filled and the correct level achieved, the soil compaction and shear strength were recorded using the Scottish Institute of Agricultural Engineering penetrometer (Anderson *et al* 1980) at the surface, 30, 60, 90, 120 and 150 mm depths and the shear vane at 29 mm depth.

As far as possible, constant soil moisture levels were maintained by watering the soil after filling the tank and then allowing the soil moisture to equilibrate throughout the tank for several days before trial work was commenced. Soil moisture contents were monitored as necessary by sampling and oven drying at 105°C for 22 hours.

A further set of trials was undertaken to determine the depth obtained with blunt and sharp discs of 300 mm diameter with an applied force of 0.49 kN. The sharp disc was in an "as new" condition, the blunt one being squared to the thickness of the disc (4.5 mm). Four replicates were carried out.

Equipment

1) *Test trolley*

This consisted of a four-wheel frame spanning the soil tank and mounted on rails which ran the length of the test area (fig 3). A pivot bar was mounted within the frame; this extended the width of the soil tank and carried a support arm. The disc under test was fitted to this support arm so that it could be moved to different positions across the tank.

A measured force was applied directly above the disc (fig 4), but, to enable a direct reading of the force to be taken, the weight of the support arm was counter-balanced.

The trolley was driven by means of a mechanical winch incorporating a variable speed gearbox so that different forward speeds could be used.

2) *Instrumentation*

To measure the depth of disc penetration, a rotary potentiometer was used (fig 5) calibrated for each of the three disc sizes. As disc depth increased, the rotation of the potentiometer similarly increased, through being attached to the coulter depth arm, resulting in higher voltages being recorded by a pre-calibrated chart recorder. The chart recorder was mounted on the rear of the trolley to monitor this variation in the depth of the disc.

Details of parameters investigated

Discs with diameters of 200, 300 and 400 mm were pulled at constant forward speeds of 0.89, 1.34 and 1.79 m/s. The forces required to obtain depths of approximately 25, 38 and 50 mm were recorded.

Results

The soil compaction levels for experiment 1 are given in table 4. These indicate that compaction increased with depth down to 60 mm and then decreased thereafter. However, since no runs were undertaken at depths greater than 45 mm the increase of compaction with depth must be taken into account when considering the results obtained from the parameters under investigation. The results of experiment 1 are given in table 5 and fig 6. These indicate that as forward speed was increased above 0.89 m/s a greater downward force was required to maintain depth ($P \leqslant 0.05$). The differences in force required to maintain a set disc depth between forward speeds of

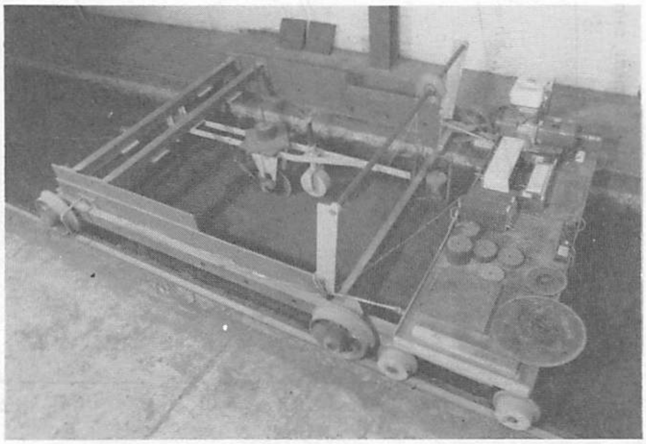
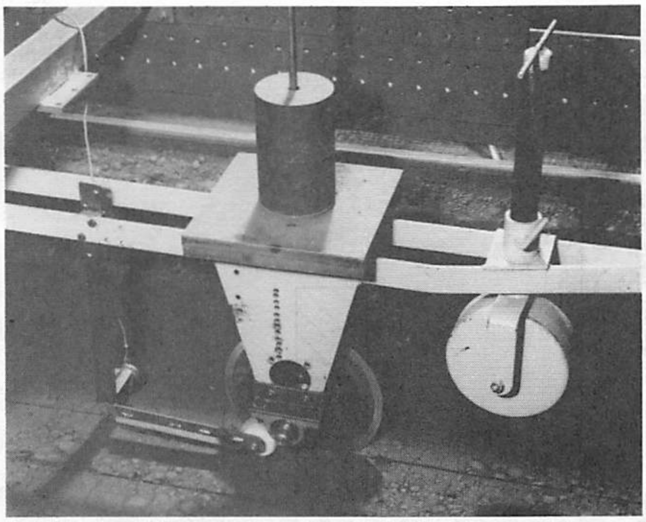


Fig 3 Soil tank test trolley

Table 3 Soil conditions: red loam (Hobkirk series)

Maximum dry bulk density*		1750 kg/m³
Mean moisture content		15.0% (w/w)
Moisture content range		13.5–16% (w/w)
	Particle size distribution	
	Size, mm	*Retained, %*
Gravel	> 2.0	2
Sand	2.0–0.06	50
Silt	0.06–0.002	34
Clay	< 0.002	14

**Proctor compaction test*



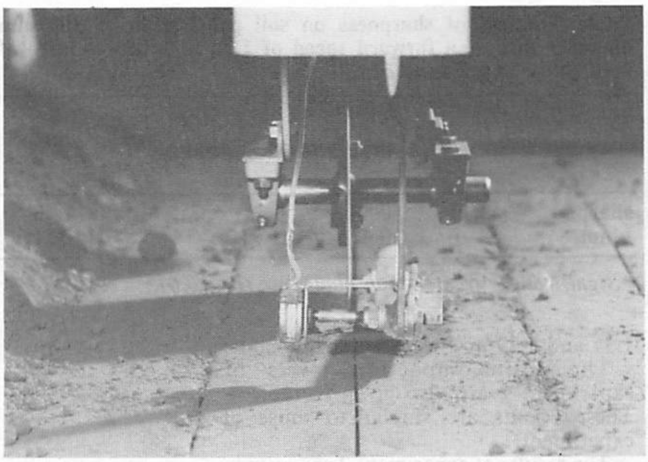


Fig 4 (left) Detail of equipment for applying the force
Fig 5 (above) Equipment for measuring depth of disc coulter

Table 4 Soil compaction and strength

Experi-ment no	*Penetrometer readings*			*Shear vane at 29 mm*	
	Depth, mm	*Cone index, kPa*	*SE*	*kPa*	*SE*
1	0–30	1267	1.52		
	30–60	1519	1.20		
	60–90	1372	1.27	46.28	1.94
	90–120	1253	1.06		
	120–150	1144	1.28		
2	0–30	1540	1.94		
	30–60	1606	1.29		
	60–90	1465	1.63	42.86	2.98
	90–120	1350	1.88		
	120–150	1241	1.96		

NB *Cone Index: the mean of 108 readings in experiment 1 and 216 readings in experiment 2 measured with 120 mm² cone of 13° angle.*
Shear Vane: the mean of 108 readings in experiment 1 and 243 readings in experiment 2.

Table 5 Effect of varying forward speed and forces on 300 mm disc on soil penetration — experiment 1

Speed, m/s	*Force/Depth parameters*		*Mean*	*SE*
0.89	Force,	kN	0.56	0.04
	Depth,	mm	39.90	4.12
1.34	Force,	kN	0.61	0.04
	Depth,	mm	39.90	3.45
1.79	Force,	kN	0.66	0.05
	Depth,	mm	42.80	4.01

Table 6 Effect of diameter and force on disc penetration at a forward speed of 1.34 m/s — experiment 2

Disc diameter, mm	*Applied force, kN*	*Mean depth, mm*	*SE*
200	0.34	22.3	0.95
	0.49	35.1	1.11
	0.64	41.1	1.06
300	0.34	19.6	2.16
	0.49	28.3	2.74
	0.64	40.7	3.49
400	0.34	16.4	1.48
	0.49	26.4	1.61
	0.64	37.9	2.80

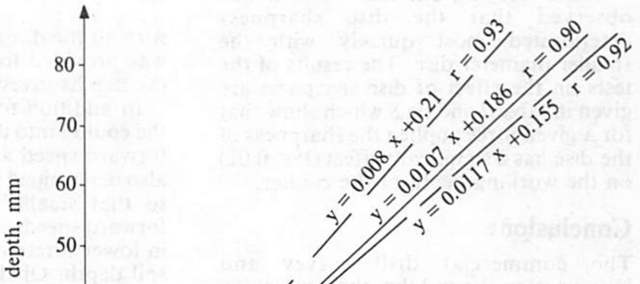


Fig 6 Effect of vertical force and forward speed on depth for 300 mm diameter disc

Fig 7 Effect of vertical force and disc diameter on coulter depth at a forward speed of 1.34 m/s

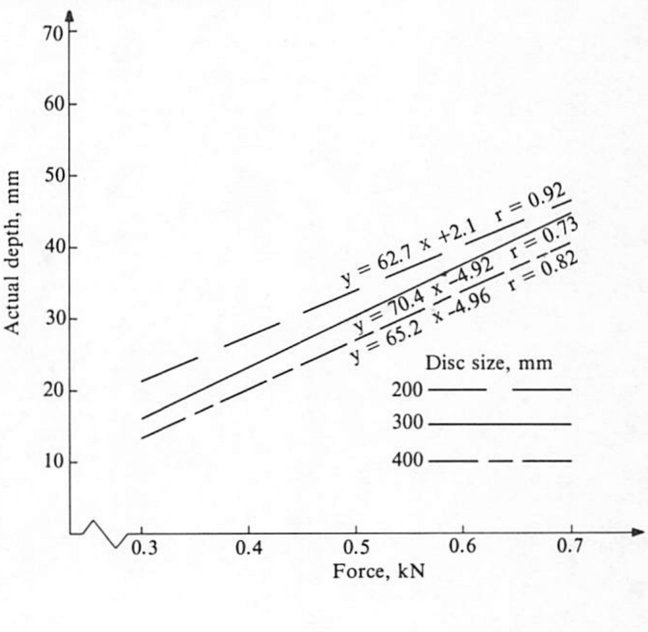


Table 7 Effect of sharpness on soil penetration of 300 mm diameter disc at a forward speed of 1.34 m/s with a force of 0.49 kN — experiment 2

Disc sharpness	*Force, kN*	*Mean depth, mm*	*SE*
sharp	0.49	*33.5	2.73
blunt	0.49	5.6	2.51

**Significantly greater than blunt disc ($P \leqslant 0.01$)*

1.34 and 1.79 m/s were not significant.

The soil compaction levels of experiment 2 are also given in table 4. These results are similar to those of experiment 1.

The results of experiment 2 are given in tables 6 and 7 and in figs 7 and 8. The former table and figure show that as disc diameter is increased so the force required to penetrate to a given soil depth also has to be increased.

While carrying out this work, it was observed that the disc sharpness deteriorated most quickly with the smaller diameter disc. The results of the tests on the effect of disc sharpness are given in table 7 and fig 8 which show that for a given force applied the sharpness of the disc has a significant effect ($P \leqslant 0.01$) on the working depth of the coulter.

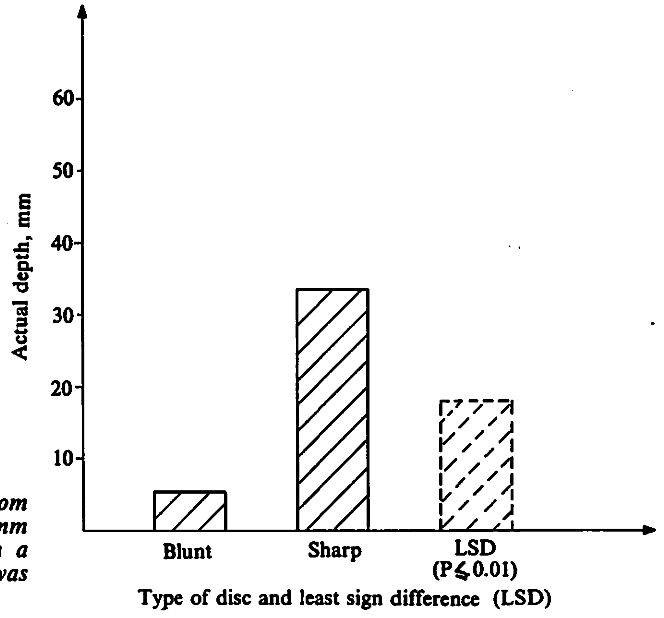


Fig 8 Mean depth from sharp and blunt 300mm diameter discs when a force of 0.49 kN was applied

Conclusions

The commercial drill survey and investigation showed that there was not a direct relationship between maximum unladen weight on each coulter and the maximum force available to obtain a pre-determined coulter depth. Whereas the Moore Uni-drill had the lowest unladen weight per coulter, the method of transferring machine weight from the land wheels, press rolls and drawbar resulted in this drill giving the greatest penetration force per coulter for most pre-determined depths. The coulter parameter investigation showed that, with all the direct drills, sufficient weight was provided for coulter penetration at the depths investigated in the soil tank.

In addition to the force used to press the coulter into the soil, the disc diameter, forward speed and sharpness of the disc also determined the depth of penetration, so that smaller disc diameters, slower forward speeds and sharper discs resulted in lower forces required to reach a given soil depth. Of the three parameters, the sharpness of the disc appeared to have the greatest effect from the limited information available. The force required for soil penetration could be considerably less if a method of toughening or self-sharpening the discs were used. Draught would be reduced and, consequently, fuel costs.

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The practical assessment of timeliness penalties for machinery selection purposes

K Eradat Oskoui

Abstract

THE development, the evaluation and the application of a practical and comprehensive method of calculation of timeliness penalties using simple and readily available data are described. The proposed method is based on the results of field experiments carried out over a period of up to 10 years throughout the United Kingdom. By means of this approach, a unique yield/time function can be obtained for a given crop, variety and location. This function can then be used to calculate the timeliness penalties at various sowing dates. Emphasis is made only on the calculation of the yield loss of cereals due to late sowing to demonstrate the feasibility of the proposed procedure; the results of experiments for winter and spring barley and winter wheat in England and Wales, and for spring barley under Scottish conditions, were analysed.

Introduction

A basic criterion of farm machinery selection is to establish a machinery system which is capable of completing all the operations during a crop growth cycle in order to maximise the farm income. Dividing the number of hectares to be cropped by the number of working hours gives the size of machine required in terms of its capacity in ha/h. The problem is not all that simple, as one may not or perhaps cannot have a single figure for the number of working hours available. This is due to the fact that agricultural operations cannot be performed at arbitrary times throughout the year. Almost every agricultural operation required for successful crop production must be timely. Untimely completion of any of these operations will cause a substantial loss of yield and quality, which ultimately will affect the farm's income. This loss is termed 'timeliness penalty' or 'timeliness cost'.

Timeliness penalties constitute a major part of the whole economy of farm machinery selection and unless its magnitude is properly evaluated and incorporated in the structure of a machinery selection programme, reliability of such a programme will be questionable.

As part of an extensive research programme carried out at the Edinburgh School of Agriculture, this paper describes the importance of the factors affecting and a practical concept for the evaluation of timeliness penalties for agricultural operations.

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Refereed paper: manuscript received 28 July 1983 and accepted in revised form 29 September 1983.

Factors affecting timeliness penalties

Edwards and Boehlje (1980) described timeliness penalties as the indirect cost of lower crop yields that occur because farm operations such as planting and harvesting are not completed during the optimal time period. This is due to the fact that all of the 'TIME' potential during the growth season cannot be utilised to complete the agricultural operations. A substantial amount of 'TIME' can be lost due to the effect of the following factors:

(a) changes in the weather conditions during the working season such as heavy rainfall, snow, sleet, strong winds and severe drought;
(b) labour and machine reliability, availability and management such as breakdowns, servicing, transport, queuing, turning and the size and the efficiency of the system;
(c) social and political situations such as holidays, strikes, etc;
(d) availability of seed, fertiliser, chemicals, etc.

Factors mentioned in categories (a) and (c) are out of the farmer's control and very little can be done to improve or to avoid them, whilst most of the factors in category (b) and category (d) can be manipulated in order to reduce the 'lost time'. A major improvement can be achieved by increasing the size (capacity) of the machinery system. This objective can be achieved by accepting that a sizeable increase in the capital investment of the farm will have to be made in order to maintain the profitability of the farming enterprise. The extra investment in bigger machinery should not exceed the amount of the reduction in the timeliness penalties.

Timeliness penalties can occur at all stages of the crop production cycle. Untimely completion of seed bed preparation will delay sowing and planting operations, which can increase frost damage for winter crops and shorten the growing season for spring crops and therefore depress yield. Too late, or early application of fertiliser or chemicals can also cause a drop in the level of the expected yield. A strong element of timeliness is associated with harvesting operations.

There has been a considerable amount of work done throughout the world in order to establish a pattern at which crop yield and quality responds to timeliness of various agricultural operations. These studies have been reviewed in previous work (Eradat Oskoui 1981).

Literature cited

The simplest method of incorporating timeliness penalties in a machinery selection programme is to define a season for every individual operation and consider the machinery system which will complete the work during that season. In this method, no account is taken of the system completing the operation outside the assigned period and this may be an unduly harsh barrier in comparison with other selection criteria.

Link (1967) proposed that the use of yield/time function is the most comprehensive procedure for evaluating timeliness cost. Sowell *et al* (1971) defined the timeliness function as a relationship

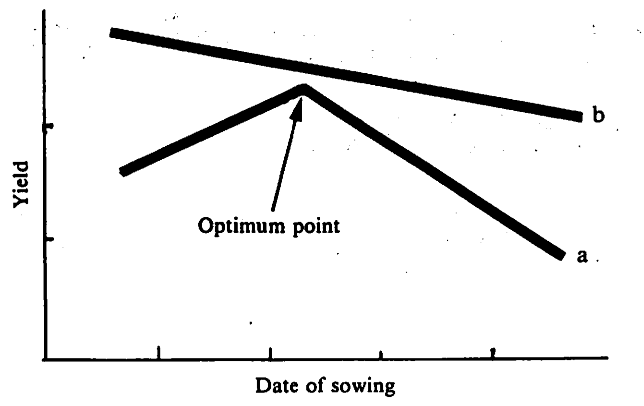


Fig 1 (Above) Two different yield/time functions suggested by Hunt (curve a) and Burrows and Siemens (curve b)

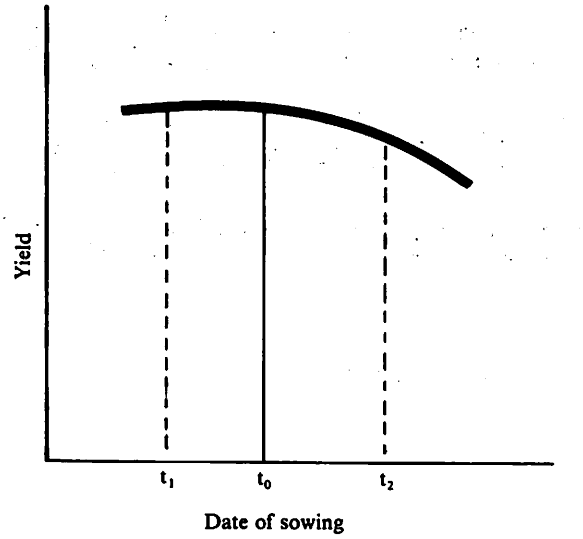


Fig 2 (right) A quadratic yield/time function (after Link 1967)

between the time of performing some operations on a crop and some measure of output, eg return, yield, etc. Hunt (1968) suggested that the yield/time function can be represented by two straight lines, one on each side of the optimum point as shown by curve "a" in fig 1. Burrows and Siemens (1974) used only one straight line. This line represented a constant decline of yield at the rate of 62.7 kg/ha per day of delay after the middle of May for Spring crops (curve "b" in fig 1).

Evaluation of timeliness penalties

Link (1967) suggested that a quadratic yield/time function exists for every timely agricultural operation (fig 2). A comprehensive review of field experiments (Eradat Oskoui 1981) confirms this theory. The general form of the equation can be expressed in the following form:

$$Y = at^2 + bt + c \qquad (1)$$

where: Y = crop yield for an operation executed at time t,
t = time at which the operation was carried out,
a, b and c = yield/time coefficients.

This relationship can be applied to most of the timely agricultural operations such as tillage, sowing or planting, spraying, fertiliser application and harvesting and is also valid for the majority of agricultural and horticultural crops. In order to study the feasibility of the method, only one operation and one crop — namely sowing of cereals in British conditions — was studied.

Abo el Ees (1978) developed a procedure to calculate the timeliness penalties for drilling operations which complemented the method used by Link (1967). According to this method, timeliness cost due to untimely sowing of a crop can be calculated by the following equation.

$$TC = (Y_0 - Y')\,A\,P \qquad (2)$$

where: TC = timeliness cost (£),
Y_0 = optimum (maximum) yield for planting or sowing operations executed at optimum time, t_0,
Y' = average yield when planting operation started at t_1 and completed at t_2,
A = area to be planted (ha),
P = price of commodity produced (£/tonne).

Optimum yield, Y_0, can be calculated by differentiating the yield function (equation 1) and setting the resultant equation to zero as follows:

$$t = -b/(2a) \qquad (3)$$

The time, t, calculated here is the same as t_0 in fig 2 and, by substituting t_0 in equation 1, the value of Y_0 can be calculated thus:

$$Y_0 = -b^2/(4a) + c \qquad (4)$$

To calculate average yield, Y', over a sowing period, $(t_2 - t_1)$, the yield function (equation 1) can be integrated with respect to time over the given period so that:

$$Y' = \frac{\int_{t_1}^{t_2} Y(t)\,dt}{t_2 - t_1} \qquad (5)$$

Abo el Ees (1978) solves this equation and found that the following equation can be used to calculate average yield over the time span $(t_2 - t_1)$ so that:

$$Y' = a\,t_1^2 + D\,t_1 + Q \qquad (6)$$

where:
$$D = a\,L + b \qquad (7)$$
$$Q = aL^2/3 + bL/2 + c \qquad (8)$$
$$L = t_2 - t_1 \qquad (9)$$

By substituting values Y_0 and Y' in equation 2, the value of the timeliness penalty can be calculated by the following equation:

$$TC = (c - b^2/(4a) - a\,t_1^2 - D\,t_1 - Q)\ AP \qquad (10)$$

In order to calculate the timeliness penalties incurred by a given crop, values of the yield/function coefficients, a, b and c, must be known. These coefficients vary for different crops, operations and locations.

Numerous experiments have been carried out in the UK (Scottish Colleges and ADAS Reports) and elsewhere (Fenster *et al* 1972) to evaluate the effect of sowing date on the yield of various crops, but very limited effort has been diverted towards evaluating the magnitude of timeliness coefficients.

Data collected for Spring barley and Winter wheat under UK conditions were analysed in two stages to demonstrate the development and feasibility of the proposed concept.

Initially, an attempt was made to find a single general equation in the form of equation 1 which would provide a reasonably accurate prediction of crop yield for a given date of sowing (Witney and Eradat Oskoui 1982). Results for all the stations were processed using the following assumptions.

a) At this stage, only two crops were chosen, namely, Spring barley and Winter wheat.
b) Day one for Winter wheat was assumed to be September 1, whilst December 1 was set to be day one for Spring barley.

A regression analysis was carried out using these assumptions to determine the value of regression coefficients a and b, and the constant c. These values, together with the corresponding standard error, SE, are given in table 1. Although the coefficients a and b for Winter wheat were statistically significant, the very low correlation coefficients for both the Winter wheat (0.26) and Spring barley (0.21) highlighted the need for inclusion of another variable such as crop variety in the regression analysis.

About 50% improvement in both the correlation coefficient and the significance of coefficients a and b and the constant c was obtained when an attempt was made to account for the effect of crop varieties on the yield. This objective was achieved by expressing crop yield in terms of percentage of maximum yield for each variety. The results of this analysis are given in table 1.

Despite the improved accuracy of the predictive equation by using this approach, the large and significant constants for both equations (table 1) indicate that some other variables, in addition to the date of sowing and variety of crop, may be responsible for the remaining 50% or so variation in the crop yield.

As is well known, the chosen location is another important variable affecting the

Table 1 Regression coefficients a, b, constant c and correlation coefficient R for Winter wheat and Spring barley

Crop	Coefficient values			
	a [SE]	b [SE]	c [SE]	R
(i) Yield in tonnes per hectare				
Winter wheat	-8.15×10^{-4} [-2.63×10^{-4}]	7.381×10^{-2} [2.49×10^{-2}]	3.895 [5.15×10^{-1}]	0.26
Spring barley	-2.78×10^{-5} [-4.08×10^{-5}]	-6.88×10^{-4} [7.69×10^{-3}]	4.752 [3.19×10^{-1}]	0.21
(ii) Yield as a percentage of maximum yield for each variety				
Winter wheat	-9.8×10^{-3} [-1.4×10^{-3}]	9.08×10^{-1} [1.45×10^{-1}]	75.40 [3.30]	0.48
Spring barley	-2.34×10^{-3} [4.6×10^{-4}]	3.17×10^{-1} [8.17×10^{-2}]	87.13 [3.42]	0.50

pattern of yield/time function. The results of various experiments also indicate that a given variety of crop sown in a given soil type and conditions and similar dates produced very different yields for different locations throughout the country. Therefore, this factor was taken into account in the third stage of the analysis. A different form of equation 1 was assumed and regression analysis of the following form was carried out:

$$Y = a' (m - t)^2 + b' (m - t) + c' Z + d' \quad (11)$$

where: Y and t are as defined for equation 1,
a', b', c' and d' = coefficients,
m = optimum planting date for a given variety and location,
Z = expected yield if planting carried out during the day, m.

For practical purposes, values of maximum yield time, m, and maximum expected yield, Z, can be obtained from advisory publications prepared for each crop and variety for Scotland, and for England and Wales, by the Scottish Agricultural Colleges and Agricultural Development and Advisory Services, respectively.

In this analysis, results for Winter barley in England as well as some results for Spring barley under Scottish conditions were incorporated.

High correlation coefficients and low standard errors obtained for this analysis indicate that an equation in the form of equation 11 can be used to predict the changes in crop yield due to variations in the date of sowing for a given crop variety and location.

In order to unify the results and simplify the comparison, January was chosen as day one for all the analyses (Winter and Spring crops). Crop yield was expressed in tonnes per hectare. Results of the analysis are given in table 2.

Equation 11 is expanded and rearranged so that:

$$Y = -a't^2 - (2a' m + b')t + a' m^2 + b' m + c' Z + d'$$

By comparing this equation with equation 1, the values of the coefficients a and b and the constant c can be expressed in the following format:

$$a = -a' \quad (12)$$

$$b = -(2a' m + b') \quad (13)$$

$$c = a' m^2 + b' m + c' Z + d' \quad (14)$$

Using values m and Z for each variety and location together with the values of regression coefficients a', b' and c', and the constant d' from table 2, the coefficients a and b, and the constant c can be calculated for every crop and location.

This facility the development of a unique yield/time function for every crop, variety and location, which can be utilised in equation 10 to calculate timeliness penalties of sowing and planting for that particular situation.

Results and discussion

Spring barley

Sowing Spring barley as early as possible ensures a significant increase in grain yield due to early establishment and early maturing. This creates more flexibility for harvesting operations and reduces possible crop damage through late harvesting or not harvesting at all.

Field data collected from five different experimental stations throughout England and Wales was analysed individually and collectively (ADAS, 1964–80). In general, a steady decrease has been recorded for the yield of Spring barley due to late sowing. On a few occasions sowing too early (early January) resulted in about a 10% decrease in grain yield.

A regression analysis using equation 11 was carried out for the data from each field and all data together. The variation in regression coefficients between individual fields was too small to justify the use of separate equations for each field. When all data was analysed together, a higher correlation coefficient, more significant regression coefficients and a less significant constant were obtained (table 2).

This equation was used to calculate crop yield for various dates of sowing and the predicted and actual results are plotted in fig 3. Out of 179 points, 7 points (4.00%) were predicted outside ±20% boundary lines. A correlation coefficient of 0.86 was obtained between the predicted and measured data.

Winter barley

This crop also showed a positive response to early sowing in all four situations (ADAS, 1974 and 1980). Similiar analysis was carried out for the results obtained from Boxworth, Gleadthorpe, Bridgets and Arthur Rickwood Experimental Stations. The use of a single equation (11) for all the data was supported by the good prediction of the experimental results. Out of 61 points, all were predicted within a ±20% boundary (fig 4). A correlation coefficient of 0.94 was obtained between the predicted and the actual data.

Winter wheat

There is clear evidence in favour of early sowing of Winter wheat. This can be attributed to the fact that early sowing provides a sufficient amount of time for crop establishment before ground frost prevails. This also brought forward crop maturity before the commencement of drought in dry years.

A substantial amount of data available in the ADAS literature obtained from Rosemound, Boxworth, Drayton, High

Table 2 Regression coefficients a', b' and c' and the constant d' and correlation coefficient R for Winter what and barley in England and Wales and Spring barley for England and Scotland.

Crop	*a'* [SE]	*b'* [SE]	*c'* [SE]	*d'* [SE]	*R*	*Degrees of freedom*
Winter wheat	-5.6×10^{-4} [4×10^{-5}]	-1×10^{-2} [1.4×10^{-3}]	9.58×10^{-2} [2.7×10^{-2}]	3.4×10^{-2} [1.4×10^{-1}]	0.94	218
Winter barley	5×10^{-5} [9×10^{-5}]	1.4×10^{-2} [5.3×10^{-3}]	8.4×10^{-1} [4.2×10^{-2}]	6.8×10^{-1} [2.7×10^{-1}]	0.94	57
Spring barley	-2.4×10^{-4} [4×10^{-5}]	1.84×10^{-3} [1.28×10^{-3}]	1.0 [4.6×10^{-2}]	1.3×10^{-2} [1.94×10^{-1}]	0.86	175
Spring barley (Scotland)	-3.6×10^{-4} [1.1×10^{-4}]	-1.02×10^{-2} [5.3×10^{-3}]	8.1×10^{-1} [1.38×10^{-1}]	4.7×10^{-1} [7.06×10^{-1}]	0.77	39

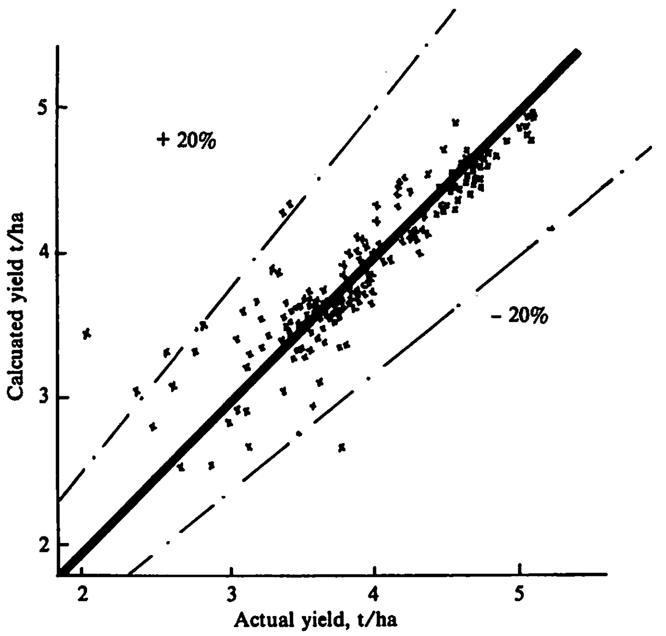


Fig 3 Actual and calculated values of crop yield of Spring barley using equation 11

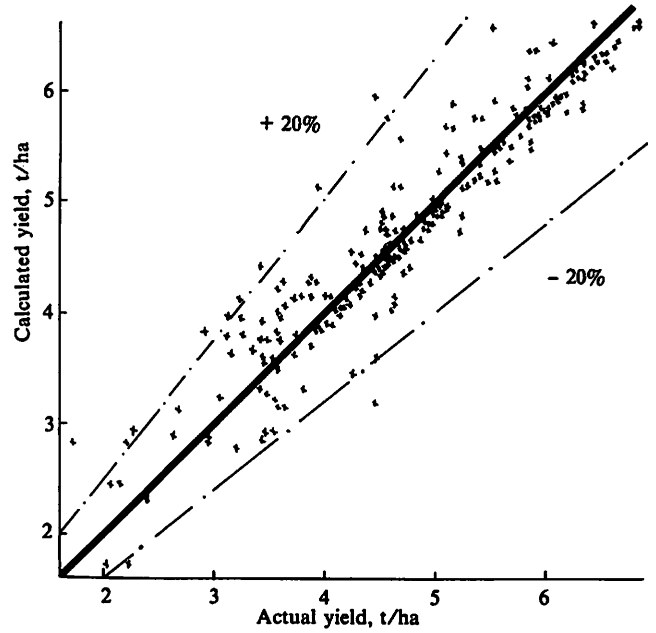


Fig 5 Actual and calculated values of crop yield of Winter wheat using equation 11

Mowthorpe, Bridgets, Arthur Rickwood and Gleadthorpe was analysed in the same manner as Winter and Spring barley (ADAS, 1965–69, 1971 and 1974).

The pattern of the response of the crop yield to the date of sowing of Winter wheat was somewhat inconsistent. Results of the experiments favoured the earliest possible sowing dates (late August or early September).

Equation 11 was also fitted to this data and very significant regression coefficients and insignificant constants were obtained. As shown in fig 5, only 10 points out of 222 data points were predicted outside the boundary of ±20%. This amounts to only 4.5% of the total data.

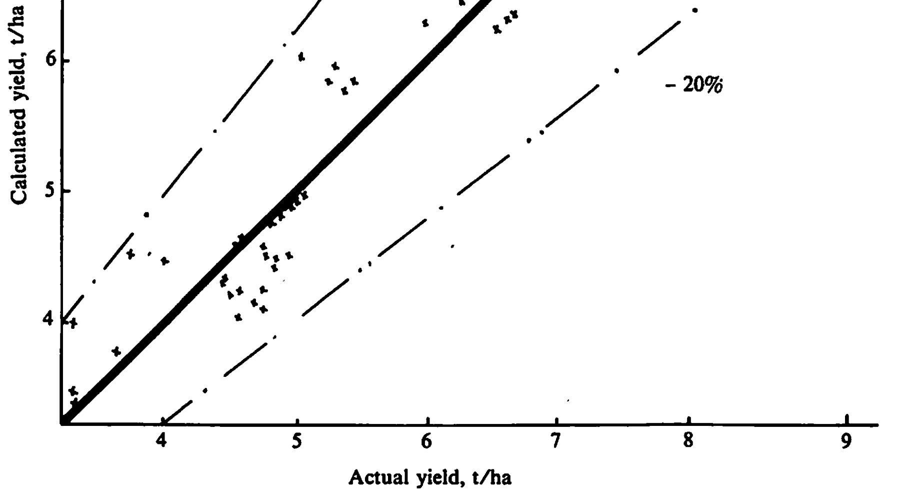
The coefficient of correlation between the predicted and the actual data for this crop was 0.94.

Spring barley (Scotland)

Results of experiments carried out at the North of Scotland College of Agriculture (1982) were analysed and regression coefficients for equation 11 were determined. Only data for Spring barley was used at this stage. Further work is in progress to obtain similar analysis of other crops, operations and locations both in the UK and overseas. As shown in fig 6, out of 40 data points, all were predicted within a ±20% boundary. Only 9% of the data fell outside ±10% boundary.

The correlation coefficient between the predicted and actual data for Spring barley under Scottish conditions was 0.77. As an example the results of this experiment, together with the predictive equation relating to this situation, are given in appendix A.

Fig 4 Actual and calculated values of crop yield of Winter barley using equation 11



Conclusion

A practical and simple means of predicting timeliness penalties of agricultural operations is very useful and provides substantial help in planning agricultural operations, selection of agricultural machinery, and decision making. This paper proves that such an equation can be developed, if the right variables are chosen. Regression coefficients supplied in table 2, combined with two other readily available variables, namely, maximum yield and recommended optimum time of sowing, can be used to calculate crop yield at a given sowing rate, as well as the unique regression coefficients for equation 1 and, therefore, a unique yield/time function (fig 7). These coefficients, in turn, can be used to calculate the crop timeliness penalties for a given variety, location and crop type by means of equation 10. Sowing operations for cereals were chosen to demonstrate the feasibility of this approach but a similar approach can be adapted to calculate timeliness penalties of most agricultural operations — such as application of chemicals and fertiliser, and harvesting operations — more easily and accurately.

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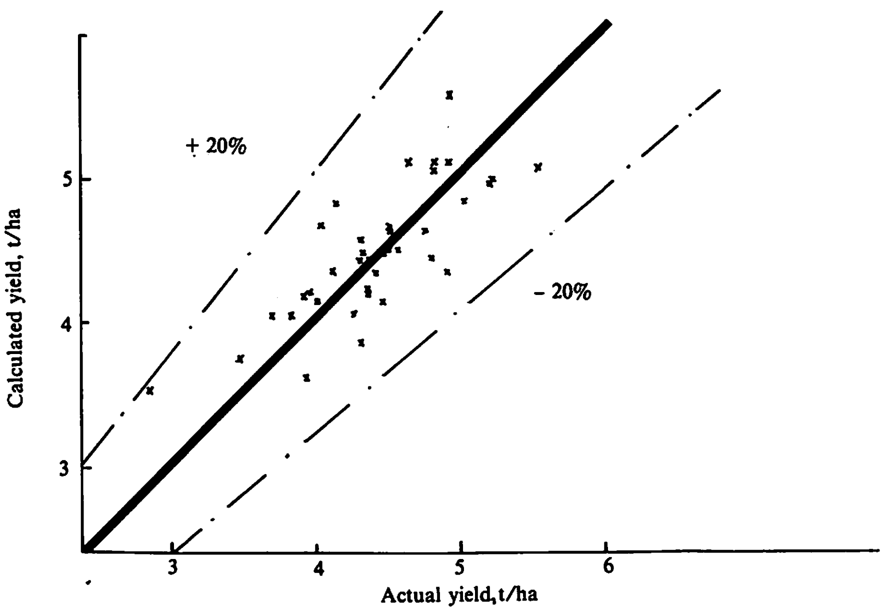

Fig 6 Actual and calculated values of crop yield of Spring barley for Scottish conditions using equation 11

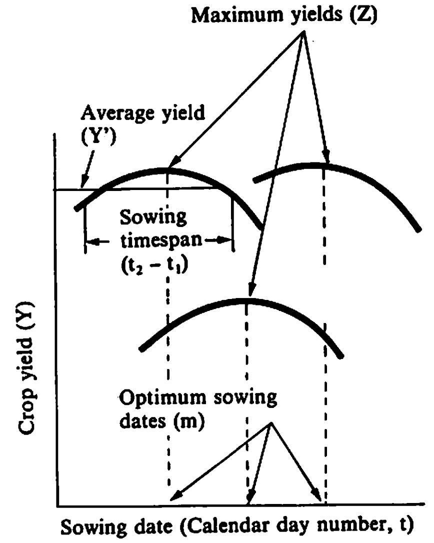

Fig 7 Three similar crop yield functions showing different maximum yields, optimum sowing dates and an average yield for a time span when sowing is in progress on three different geographical locations

Appendix A Actual and calculated yields, together with sowing date and day number for Spring barley under Scottish conditions. The maximum yield and the sowing day number for maximum yield are shown in bold print.

Variety	*Date*	*Sowing day no.*	*Actual yield, t/ha*	*Calculated yield, t/ha*
Maris mink	1 Mar	60	4.12	4.64
	8	67	5.33	4.80
	15	74	5.28	4.93
	22	**81**	**5.57**	5.02
	29	88	4.72	5.07
	5 Apr	95	4.99	5.09
	12	102	4.88	5.07
	19	109	4.84	5.02
	26	116	5.23	4.93
	3 May	123	5.08	4.83
Ymer	1 Mar	**60**	**4.82**	4.41
	8	67	4.35	4.46
	15	74	4.53	4.48
	22	81	4.49	4.46
	29	88	4.35	4.41
	5 Apr	95	4.48	4.32
	12	102	4.37	4.19
	19	109	4.39	4.03
	26	116	4.33	3.83
	3 May	123	3.97	3.60
Proctor	1 Mar	60	4.56	4.33
	8	67	4.24	4.45
	15	**74**	**4.97**	4.54
	22	81	4.41	4.60
	29	88	4.12	4.62
	5 Apr	95	4.53	4.60
	12	102	4.33	4.54
	19	109	4.48	4.46
	26	116	4.14	4.33
	3 May	123	3.94	4.17
Ingrid	1 Mar	60	3.75	4.05
	8	**67**	**4.48**	4.13
	15	74	4.00	4.18
	22	81	4.43	4.20
	29	88	4.03	4.18
	5 Apr	95	4.04	4.13
	12	102	3.85	4.04
	19	109	3.94	3.91
	26	116	3.99	3.75
	3 May	123	2.86	3.56

Corresponding equations for each variety of Spring barley for Scottish conditions are as right:- →

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Maris mink
$Y = -0.00035t^2 + 0.0685t + 1.831$

Ymer
$Y = -0.00036t^2 + 0.0534t + 2.499$

Proctor
$Y = -0.00036t^2 + 0.06353t + 1.811$

Ingrid
$Y = -0.00036t^2 + 0.05849t + 1.83$

Testing potato harvesters in the Federal Republic of Germany

A Specht

Summary

THE testing of potato lifters in the Federal Republic of Germany has been undertaken by the German Agricultural Society (DLG) on a voluntary basis since 1894. Spinners and elevator diggers were tested up to the Second World War, but subsequently tests have been almost exclusively of potato harvesters. Since 1956, these tests have been carried out by the KTBL Experimental Station at Dethlingen on behalf of the DLG.

Up to 1982, 34 models of harvester developed for German agriculture received "DLG approval". This is valid for a five-year period and can be extended for only one further period of five years.

At the KTBL Research Station at Dethlingen, which is concerned exclusively with the mechanisation of potato growing, the DLG test always requires a one to two-year evaluation during which further modifications to the machine are permitted. The official test then follows within one year.

After the appropriate registration, the firm must pay the test fee which, for potato lifters, is 25% of the retail price.

Test farms providing at least 25 ha are required, with as many different conditions as possible, and having lifters already tested. In this way, corresponding damage samples can be taken from the lifter, and measurements of losses made, in order to arrive at the optimum adjustment of the machine.

Following this set of tests, the measured test performance commences. For this purpose a uniform, completely stone free field is set out with the test areas required. For measuring tuber damage, the same mixture of stones has been introduced into the potato ridges for two decades, giving potato:stone ratios in the following steps 100:25, 100:50 and 100:100 by number. For at least three different forward speeds, the ratio of work of three pickers and of the separating mechanism is determined. To establish tuber damage levels, four samples of 25 kg of each variety are taken from the lifter before reaching the delivery point and stored for at least four weeks before testing. After being put through a peeling machine to make the damage more visible, the damage is classified into light (1.7 to 5 mm deep), and severe (over 5 mm deep).

Losses are established by examining four replicates of an area of 10 m^2, and are divided into surface and buried tubers over 25 mm.

Lifting on slopes involves the measurement of the deviation of the lifter from the centre of the furrow while working across the slope.

The test is completed by a survey of 30 users of the same type of machine, and by an investigation of the safety of its design.

The observations on its work, the measured results and the technical data are brought together from the various sources and evaluated for the DLG Test Report — which requires the precise following of the above procedures. The Report must be put before a Test Committee, comprising representatives of the agricultural machinery industry, the plant breeding station, the advisory service and farmers. After being agreed by the Test Committee, the Test Report is sent to the firm requesting the test. Only after the agreement of all these participants is the machine "approved", and the report printed.

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The conference paper was translated from German by Dr David Blight, Director, Scottish Institute of Agricultural Engineering.

Potato lifters must lift the potato ridge, separate the tubers from soil, haulm and weeds, and allow loss-free harvesting. Spinners and elevator diggers leave the tubers to be separated by hand from amongst the unwanted material. Harvesters, on the other hand, separate clods and stones from amongst the potatoes; other rubbish must be removed by hand. The tubers are delivered to containers of various sizes in the form of boxes, sacks, bulk hoppers, large boxes or trailers.

Potato lifters have been tested on a voluntary basis by the German Agricultural Society (Deutsche Landwirtschafts Gesellschaft — DLG) since 1894. Further tests of spinners followed in 1899, 1908, 1913, 1926 and 1931. Just after the Second World War, testing re-started with two lifters using spider-wheels. In 1954, the DLG carried out a series test of pto-driven potato harvesting machines, comparing five elevator diggers, and three harvesters. The tests were carried out on behalf of the DLG by the Institute of Agricultural Engineering of the University of Bonn. In this series test, the basic procedures for further testing were established.

The KTBL Research Station at Dethlingen was established in 1955, charged with the further development and testing of machinery for potato growing, latterly commissioned by the DLG. After a number of years of comparative testing, the most extensive series test to date was carried out in 1961 when seven harvesters and one elevator digger successfully completed the test. The most successful harvester was the 'WISENT' made by Hagedorn, of which now more than 30,000 have been built over almost two decades. Of harvesters of other makes featured in this test, more than 10,000 have also been built. The title 'DLG anerkannt' (DLG approved) was given to one harvester in 1964, and to four in 1968.

The first two-row harvester received 'DLG approval' in 1973. At this time, much effort was put into improving the capacity of single row lifters by increasing the sieving and separating area and the capacity of the bulk hopper. In 1976, a series test was conducted of six single-row machines classified as of the highest capacity. In 1980, nine more types of harvester were tested and, in 1982, two single-row and one two-row harvester. Thus, up to 1982, a total of 34 harvesters had undergone the complete DLG test.

The companies Bergmann, Grimme, Hagedorn, Niewöhner and Tröster have all participated continuously in these tests and today offer a wide range of models.

The DLG approval has a validity of five years and can, on request, be renewed for one further five-year period. The charge for testing harvesters is 25% of the price of the machine. If, at the same time, other machines in the same type series are offered for test, each of these is charged at 50% of the otherwise appropriate test fee. For several years, series tests of machines of similar construction and capacity have been available at a reduced test fee. Such a series test was conducted in 1976 with single-row harvesters categorised as of the highest capacity. For a single extension of test, charges are levied only if extra costs are incurred.

DLG testing at the KTBL Experimental Station, Dethlingen, takes place over one or two years of comparative investigations to accommodate modifications and improvements, thereby facilitating the opportune introduction of improvements which enhance machine performance. For this reason, negative opinions are only very rarely expressed in test reports, while the manufacturer can make an early decision as to whether the machine shall be entered for the DLG test.

Up to 1970, two machines were demanded for the DLG test. One machine was used for farm tests, the other for measured tests. Measurements of one machine established the technical specification and baselines for the more comprehensive tests. This machine was then put on a farm already operating a similar machine. In this way, the familiarisation period was considerably reduced. For single-row harvesters, a test area of 25 ha is required.

Nowadays, to save expense, a machine specifically for measured tests is not demanded. The machine under investigation is placed on farms where machines, which have already been awarded DLG approval, are in use and can be used for comparison. The base measurements for the more comprehensive investigations have been discontinued, since 25 ha are inadequate for this purpose. During the farm tests, tuber samples are regularly taken, losses measured, and work rate established in order to arrive at the optimum working conditions for the measured tests. These measurements are made under as wide a variety of conditions as possible. The test is completed with measured findings on a specially prepared test field (fig 1). Additionally, a questionnaire is completed by 30 farmers, dealing with many matters of practical experience.

Following the general improvement in design, no special differentiation is made between normal and difficult lifting conditions.

For *ridge uptake*, the required depth of working, spillage, soil flow over the share, and liability to blockage from haulm are established. Comparable performance under weedy conditions is also important. The length of travel required to reach working depth is so small that it can be disregarded.

Maintenance of *working depth* must be independent of the towing tractor. If this is not the case, it is a point against the machine. The test is only carried out where the setts have been planted by a machine with floating furrow openers to ensure independent depth control.

Poor lateral control is indicated by the proportion of cut tubers and poor depth control by the proportion of chopped tubers.

No objective criterion for *sieve capacity* has yet been established, since soil sieving and the proportion of damaged tubers must be considered together. Points to be evaluated include the steepness, length and breadth of the web. It is also important to consider the gap between the web rods, which influences tuber losses.

In evaluating *haulm removal*, performance with various quantities of green haulm, pulverised haulm, chemically treated haulm and greater or lesser amounts of weed is noted. Since 1960, only fields with chemically treated haulm have been used in the measured tests, the criterion being tuber loss.

The *separation of stones and clods* is subjectively evaluated under practical conditions. The measured runs are made in a field specially prepared for the purpose. Depending on the type of separating mechanism, stones are introduced into a stone-free potato ridge to give the required potato:stone ratios. For two decades, the same stones have been used, which are generally representative of potato growing areas with hard stones. The stones are prepared in batches of 250 in 25 kg potato boxes and, after establishing the number of potatoes in the ridge, are placed in the ridge to give potato:stone ratios of 100:25, 100:50 and 100:100 (fig 2). The measured lengths used for this purpose are 25 m. Four replications are made and forward speeds of 1.5, 2.5, 3.5 and 6 km/h are used (fig 3). This assumes a good, easily flowing soil. In these measurements three pickers are used, and are always placed on the harvesters so as to give comparable positions. We always try to use the same pickers. The effort required of the pickers, in number and weight of objects handled, is measured, together with the number and weight remaining with the tubers and the proportion of wrongly directed tubers with the machanically separated material. This method of testing has proved itself over many years and has given objective results, but the optimum adjustment of the separating mechanism must be adequately investigated beforehand.

No objective criterion has yet been established for clod separation since the hardness of the clods is strongly dependent on soil type and water content.

Tuber losses are determined by collecting those tubers lying on the surface, and exposing and collecting the buried tubers (fig 4). Tubers larger than 25 mm are considered, and for several years now tubers from 10–22 mm have also been taken into consideration since they represent potential ground keepers. Generally, measurements are taken from two rows over an area of 10 m^2 with four replicates per variable.

To *determine tuber damage*, use is made of the 100 tuber rapid test and the peeler test. The 100 tuber test serves to establish the general damage levels and the

Fig 1 Field used for measured tests of potato lifters

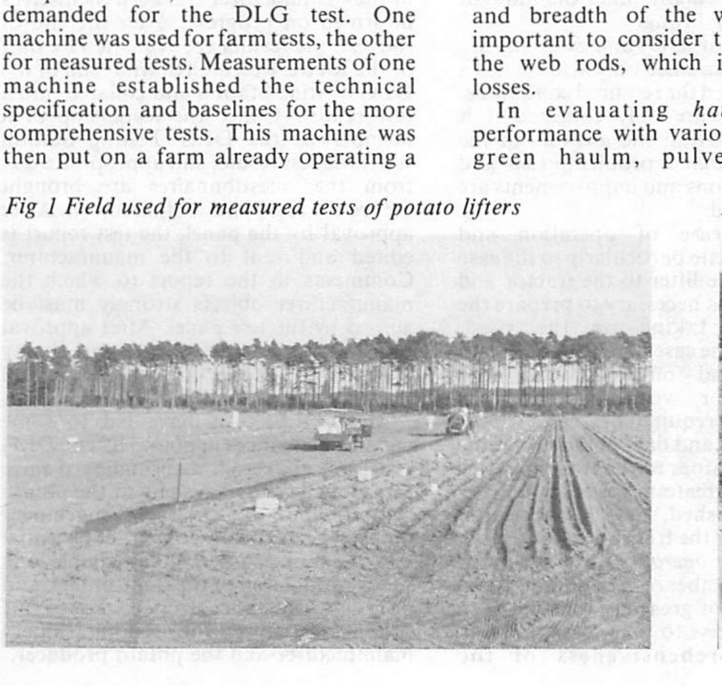
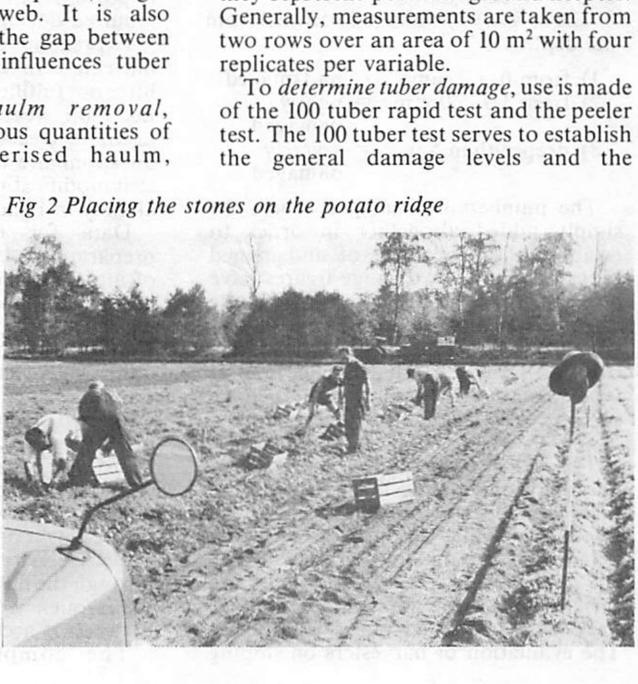


Fig 2 Placing the stones on the potato ridge



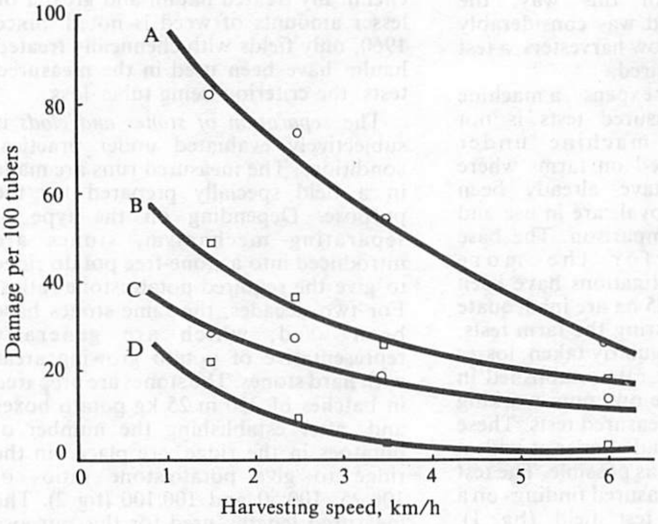


Fig 3 Damage results at various forward speeds (above)
Fig 4 Determining tuber losses (top right)
Fig 5 Measurement of power requirement (bottom right)

optimum setting of the lifter. While the test machine is on the farm, some 30 to 50 samples of 100 tubers are taken from each machine, and, as nearly as possible within an hour, in order to get a better understanding of pressure damage, these are washed and are evaluated as soon as possible after 24 hours. Damage is assessed using a peeler, all damage being included. The temperature of the tubers when lifted is always noted.

For evaluation during the measured tests, 2–3 boxes of 25 kg from each variant are stored for at least four weeks in order to ensure the development of pressure points and bruises. The damage samples are divided into 8 kg lots and peeled in an abrasive peeler at a water temperature of 20–25° C for one minute at the most, to obviate further bruising and to make all damage visible. Six replicates are taken from each variant.

After this, a knife peeler is used; three man hours suffice for 20–40 samples per day to be evaluated, depending on the degree of damage.

The *severity of damage* is defined from the depth:

1) from 0–1.7 mm = undamaged
2) from 1.7–5.0 mm = lightly damaged
3) deeper than 5 mm = severely damaged

The numbers of damaged tubers are simply added altogether in order to establish the proportion of undamaged tubers. Since 1976, damage figures have been included in the test reports. These values are comparable from year to year since, wherever possible, the values are calculated round a stated damage level. It is particularly important that the damage samples are taken at a temperature 12–14° C.

The *rate of work* is largely determined by conditions on the farm. During the farm tests, many husbandry data are established which serve as the basis for determining the rate of working.

From this, average conditions are arrived at and the appropriate data for previously tested machines determined. The evaluation of harvesters on sloping land takes as criteria the spillage losses from the share and the deviation of the wheels of the lifter. No spillage losses can be tolerated from the share, and the lifter wheels may not deviate more than 10 cm from the centre of the furrow. Further limits may be placed on the separating units, particularly when evaluating lifting up and down hill, to which counter-rotating separating arrangements are particularly sensitive.

The *power requirement* is measured at three different forward speeds using a test car from the DLG Testing Station (fig 5) for draught and pto power. For this purpose, two tractors are coupled to the harvester, one behind the other, the first tractor providing draught, the second pto power. These draught measurements have been found useful for the manufacturer, but are rarely demanded by the farmer. The highest draught is found during the journey to the stationary trailer, when machine weight and capacity of the bulk hopper is important. It is many times the draught required during lifting.

Expressions of *safety* and *durability* are difficult to make since only seldom has a lifter not fulfilled the required conditions. Data on wear are only collected if it becomes clear from the answers in the questionnaire that a problem exists and that modifications and improvements are already in hand.

Data for ease of operation and preparation relate particularly to the ease of attaching the lifter to the tractor and on the measures necessary to prepare the machine for taking on the road. Additionally, the ease of putting the share units into and out of work, and adjustment for working depth are evaluated. The required headland widths are determined and data obtained for the transfer of potatoes to the trailer. In this context, the greatest possible delivery height is established, since this sets a limit to the height of the transporter or trailer.

Daily service operations are evaluated through the number of grease nipples and the frequency of greasing, together with the ease of access to the grease nipples.

The comprehensiveness of the *instructions* and the *parts list* is determined.

Before terminating the test, the official Farm Safety Service investigates the machine to ensure that the safety regulations are observed. Potato harvesters are particularly susceptible to accidents because most of the machines require a number of pickers, and rotating parts can never be entirely adequately guarded because the pickers require easy access.

At the beginning of the test, usually after the first time the machine is put into work, a *test panel* is set up comprising one farmer and one representative from, respectively, the farm machinery industry, the plant breeding station and the advisory services. Members of the test panel have generally already had many years experience in this type of work. A representative of the manufacturer reports on the construction and specification of the machine. During the farm tests, members of the test panel and of the manufacturer can keep themselves informed on progress. After the end of the test, the results are evaluated by staff of the KTBL Research Station and of the DLG Testing Station and collated into a test report. Under the leadership of a member of the DLG Testing Station staff, the test results and appropriate text from the questionnaires are brought before the test panel and discussed. After approval by the panel, the test report is edited and sent to the manufacturer. Comments in the report to which the manufacturer objects strongly must be agreed by the test panel. After approval by the manufacturer and the Safety Authority, the report is sent to press and the manufacturer given a test document.

Most DLG tests have led to some technical advances in potato lifters. DLG tests are, above all, a springboard since the contents are of benefit to the potato grower and to the farm machinery industry. The increased market potential as a result of a successful test enable long series production of the same model, and correspondingly lower costs of production both for the machinery manufacturer and the potato producer.

The UK agricultural engineering industry and the future of the smaller manufacturing company

G H Evans

1 Introduction

IT is planned to take a brief look at the present structure and state of affairs within the agricultural machinery industry, to discuss some of the reasons for its present position and consider the possible direction of trends.

The smaller manufacturing companies within this industry are a major force in total but are under considerable pressures. Their chances of survival and expansion over the next decade are discussed.

Over the past five years, a number of studies have been made of the UK agricultural machinery industry, the first being the Department of Industry study of 1978 and the latest to be published is that conducted by the Royal Society in 1982.

These reports have shown the structure of the industry, noticed its decline in terms of trying to meet growing import penetration and attempted to analyse the reasons for the industry's present position.

2 Output of agricultural machinery

The trend of output of UK manufacturers of agricultural machinery, as measured by the Department of Industry Index of Production, was a steady decrease from 1970 to 1979 (fig 1). The main divergence from the trend was in 1973/74 when a booming domestic market allowed two years of increasing output. Since 1979, however, the Index has reflected the severity of the recession, falling from 86 (1975 = 100) to 46 in two years.

This paper was presented to the Northern Branch of the Institution of Agricultural Engineers on 8 March by Geoffrey H Evans who is Chairman of A C Bamlett Ltd, Thirsk.

3 Exports

Exports of agricultural machinery, measured at constant prices, have shown three distinct periods of activity (fig 2). From a low base in the early decade, exports rose rapidly from 1971 to 1974 and sustained this high level for the next four years. The entry of the UK to the EEC and the prosperity of European agriculture were features of this period. The third phase since 1978/79 has been a rapid decline reflecting a deterioration of agricultural situations and the growing UK uncompetitiveness.

4 Domestic demand

The domestic market for machinery in 1970/71 period was particularly depressed in the face of low farm incomes, but sales moved rapidly up during 1972/73 and were thereafter sustained at levels 40%–70% higher than in 1970 to 1979 (fig 3). Farmers' incomes have moved down consistently from the 1976 peak but investment in machinery fell back comparatively slowly until 1980 when a fall of some 25% was experienced in one year, 1981 was further depressed but 1982 has seen some recovery. 1983 should show some further improvement in demand as a result of the increase in farmers' income last year, reported to be up 45% over 1981. However, it must be remembered that this latest income level is still 25% below the 1976 level.

5 Imports of agricultural machinery

A major feature of the industry in the 1970s was the growth in import penetration (fig 4). In 1970, imports took 25% of the UK market of machinery but, today, take well over 50% with a continuing upward trend.

6 Balance of trade

On the wider Agricultural Engineers Association definition of agricultural machinery, the deficit on the balance of trade was observed in 1981 for the first time (fig 5). When converted to 1970 prices, the balance can be seen to have been deteriorating in real terms. As shown previously, the trend in UK exports has not been significantly downwards but imports have been growing steadily.

Fig 1 Index of production for agricultural machinery (1975 = 100)

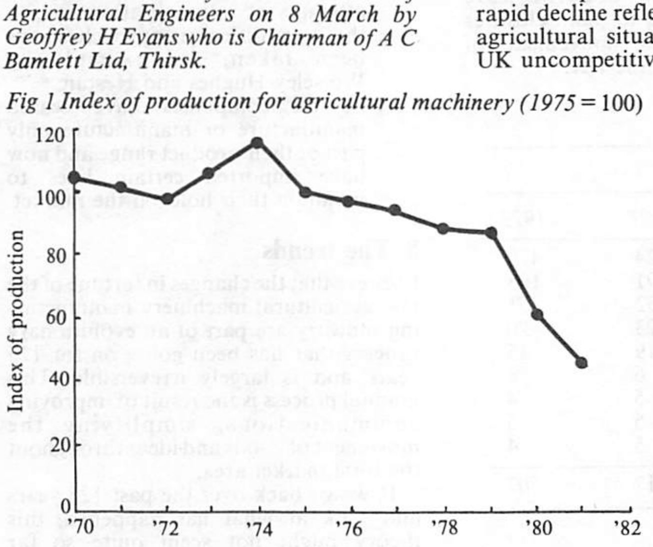
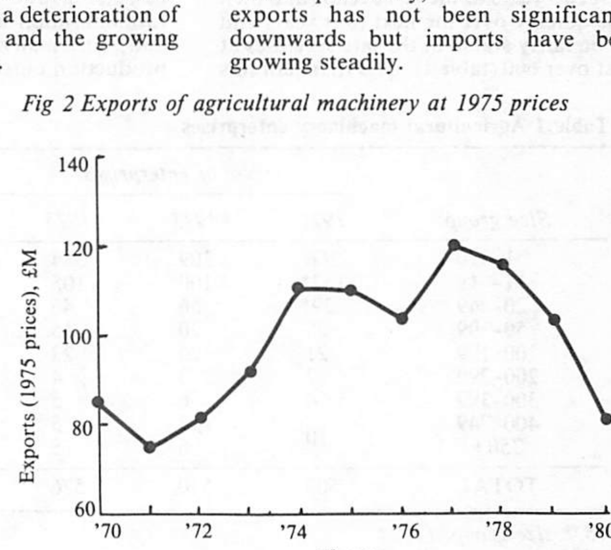


Fig 2 Exports of agricultural machinery at 1975 prices



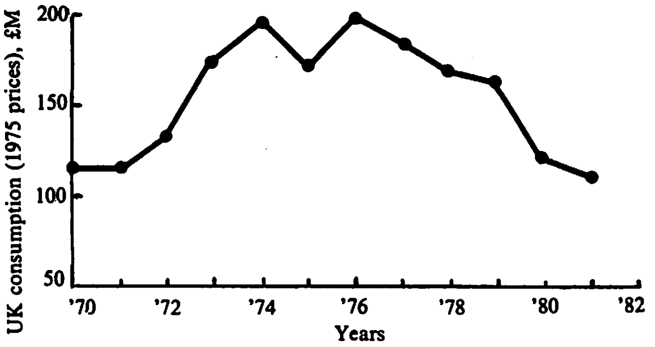


Fig 3 UK consumption of agricultural machinery at 1975 prices

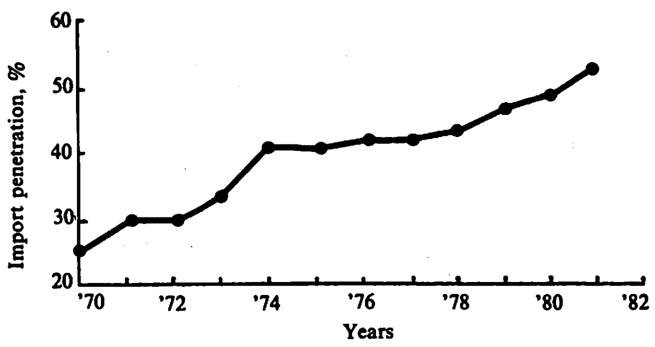
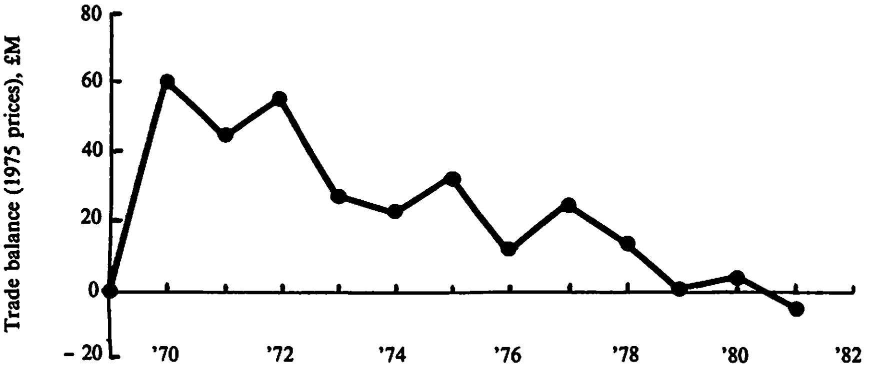


Fig 4 Import penetration as a percentage of the UK market for agricultural machinery, excluding tractors

Fig 5 The trade balance in agricultural machinery at 1975 prices.



This change of trade balance is not particular just to the agricultural machinery industry but is general across all manufacturing industries in this country. The trends with the motor car and machine tool industries are well known but the same problem exists in such diverse areas as small pleasure craft, which has a large US supply, and even into the vegetable seed area where many traditional British seed houses now market Dutch seed rather than produce our own.

7 The structure of the agricultural industry

The statistics show that the number of companies involved in agricultural machinery appeared to fall during the first two years of the last decade and then rise quickly over the next four years and to be fairly stable in the late seventies at just over 600 (table 1). Less than half this number are members of the Agricultural Engineers Association.

The main increase has been in the number of smaller companies, especially those employing ten or fewer people. This reflects a comparative ease of entry into the industry and possibly more farmer originating ventures. By 1979, 95% of all enterprises employed less than 50 people.

The previous table only goes as far as 1979 and it will have been apparent to many that, since then, there has been a serious cut back in production which has led to a reduction in number of production units and employment. In the last five years, employment within our industry has dropped from 67,000 to 45,000, a drop of one third.

It is perhaps in the multi-nationals that the greatest reduction in employment has taken place with considerable rationalisation leading to plant closures and, in many cases, movement of production outside of the UK.

Table 1 Agricultural machinery enterprises

	No. of enterprises				
Size group	*1971*	*1973*	*1975*	*1977*	*1979*
1- 10	266	309	384	424	420
11- 19	157*	100	105	91	103
20- 49	29*	56	46	52	51
50- 99	25	20	15	23	20
100-199	21	20	23	19	15
200-299	7	3	4	6	8
300-399	4	6	5	5	4
400-749 } 750+ }	10	3	5	5	5
		6	5	5	4
TOTAL	503	510	576	612	607

157 size group: 11–24*
29 size group: 25–49*

Massey Ferguson are reported, on a worldwide basis, to have reduced their labour force from 68,000 in 1976 to 29,700 at the end of 1982, a reduction of 56%. These figures will include of course disposals such as the Hanomag Construction Machinery business in Germany.

The basic structure of the UK agricultural machinery industry, as shown in table 1 has changed only slightly over the last decade. However, the recent economic recession combined with reduced markets and reduced investment by farmers has lead to recent changes which suggest that the established structure may well alter over the next years.

a) The North American multi-national companies until recently have contributed tremendously to the output and export of agricultural machinery, particularly in the areas of combined harvesters, balers, and forage machinery. However, recent rationalisation by Massey Ferguson and New Holland have a considerable influence on the overall picture and one might ask the question as to whether the multi-nationals are truly indigenous to the UK manufacturing industry.
b) There have been a number of company failures, mergers and take overs in the past two to three years. Only rarely has there been positive attempts at rationalisation and, in this area, different approaches have been taken, for example by Wolseley-Hughes and Hestair.
c) Several companies have ceased manufacture or manufacture only part of their product range and now have imported certain lines to maintain their hold on the market.

8 The trends

I believe that the changes in fortune of the UK agricultural machinery manufacturing industry are part of an evolutionary process that has been going on for 125 years and is largely irreversible. This gradual process is the result of improving communications, simplifying the movement of goods and ideas throughout the total market area.

If we go back over the past 125 years and look at what has happened, this theory might not seem quite so far fetched.

Early needs of mechanisation on farms were met by local blacksmiths who fashioned the simple ploughs and harrows of the early and mid-nineteenth century. These machines found a ready market in the local area of manufacture and history shows that machines of essentially the same type were produced by many of these small manufacturers across the country.

The coming of the railways in the mid-nineteenth century were to make it possible, for a manufacturer with a superior product, to ship it to another part of the country where perhaps the local manufacturer had let his own product development fall behind. The latter, in many cases, became a dealer for the innovative manufacturer and so they were able to stay in business.

This evolutionary process has been with us for over a century, it continues today and will continue in the future.

The main advance in this trend has been in the overcoming of national boundaries and it is commonplace for British manufacturers to add imported products to their home market range, either because their own development has fallen behind, or of the need to extend the product group to get a firmer hold on the market.

Many people hold up their hands in horror at this trend but they are just burying their heads in the sand if they seek to reverse it by any significant amount.

The multi-nationals have played a major part in this evolution, sourcing many products from many countries, so as to present a full range of equipment to their dealers.

Often these multi-nationals have bought the supplying company or extended their product base and countries of operation by such a purchase. For example, New Holland and their purchase of the Clayson factory in Belgium; Massey Harris bought Ferguson to become Massey Ferguson.

Another factor influencing the change in pattern of our industry and largely overlooked by our critics, who are scornful of our lack of inventiveness, is that many new farming systems have evolved in the larger market areas of Europe. For instance, the high input cereal systems initiated in Northern Germany and Belgium gave rise to the tramline field marking system and hence a requirement for drills, fertiliser spreaders and sprayers to have a common width factor. Metrication of operating widths caught virtually all our own manufacturers on the hop and the introduction of pneumatic fertiliser spreaders, initially in Sweden and then by Germany and France, was a forward step not matched by UK manufacturers.

On the other hand, the development of direct drilling is the result of the UK need and a strong sponsoring company, ICI, leading to the point that this country is ahead of most others in this field and our technology much sought after around the world.

I mentioned earlier the larger market area of Europe. There are said to be eight million farmers within the EEC, of whom only two hundred and fifty thousand are in the United Kingdom, that is about 3%

This shows that the UK market, although we farm to a highly mechanised standard, is a very small part of that available to a manufacturer within the EEC.

Table 2 Analysis of establishments by size, 1979

Size group	*Enterprises*	*Total employment, '000*	*Total sales and work done, £M*	*Net output Total, £M*	*Net output Per head, £*	*Gross value added at factor cost Total, £M*	*Gross value added at factor cost Per head, £*
1–10	420	1,890					
11–19	103	1,493	149.9	65.1	10,042	(a)	(a)
20-49	51	1,552					
50–99	20	1,550					
100–199	15	2,301	45.4	21.4	9,303	70.2(a)	7,984(a)
200–299	8	2,324	42.7	21.6	9,299	18.2	7,841
300–399	4	1,466	38.8	16.3	11,145	13.7	9,330
400–749	5	2,686	44.7	19.2	7,149	16.3	6,073
750 and over	4	5,961	120.0	51.2	8,592	45.4	7,623
Total	607	21,223	441.6	194.9	9.183	163.8	7.718

(a) Gross value added data relate to establishments employing 1-199.

SOURCE: Business Monitor. Report on the Census of Production 1979.

The opportunity presented by our belated entry into the EEC ten years ago, giving our manufacturers direct access on advantageous terms, was not seized upon with the effort and enthusiasm that our competitors on the Continent had been showing in the preceding decade.

We had been relying on our continuing association with the former colonial markets and their demand, in many cases, for less sophisticated machinery than that which was required for the needs of farmers across northern Europe.

Over the past twenty years our continental competitors have established a very firm foothold and have developed a number of medium sized companies who have become very firmly entrenched with high volume output of sophisticated and specialist equipment.

In this country, we do not have the companies with the status of, for example: Vicon and Lely of Holland; Taarup, JF and Konskilde of Denmark; Kuhn of France; Claas, Fahr, Rau and others from Germany.

To attempt to compile a list of British companies in the same league then you have some difficulties after you get past Howard and Ransomes.

If we are to study the successful continental manufacturers, it will be found that they all had one thing in common. They all attacked the export market with a very professional approach. The majority set up overseas marketing subsidiaries. Vicon, who employ some 500 in Holland, have a further 500 around their eleven overseas companies.

9 The smaller company

How does one measure a small company? Is it by number of employees, by sales turnover, by market share, by capital employed, or by profit? If we took the last as a yardstick, then the league table has been upset in the past year or two!

From table 2 it can be seen that 95% of the companies engaged in our industry employ fewer than 50 people, and yet they only contribute about 34% of the output. The remaining 5% of companies are getting 66% of the business. For any company to have a real chance, it must be of sufficient size to have a firm foothold in the market. This means having an effective national organisation calling on dealers, attending major shows and demonstrations, and providing a first class service to the end user.

Different products require different marketing approaches, but by and large, sales of a million pounds would be a minimum requirement to sustain the necessary attack.

Output per employee is a sound measure of company efficiency, but the national average from the table is less than £10,000 per head. One of our leading companies, Parmiter, with 150 employees achieves £44,000 per head, a remarkable achievement for a wholly manufacturing company with relatively low cost machines in their product range.

Our own organisation achieves an output per employee of £36,000 and this is with a mix of about 50% import and 50% manufacture.

So our one million pound turnover company might employ between 25 and 50 people. Sixty per cent of companies in our industry have a turnover of less than one million pounds. However, viability is not really related to size but to where the company is planning to go over the next five to ten years. Not to plan for growth is to decline.

When compared with our European competitors, 25 to 50 employees would be considered very small and I believe that to be able to compete and have a satisfactory presence overseas, we should be looking for the five million pound minimum, with say no more than 125 people.

A major reason for our decline in competitiveness in this country is that there are far too many small companies competing against each other for a very small home market. There has to be a rationalisation or, better still, a fall out of some of these smaller companies. It is rather surprising how few companies have failed or have been allowed to fail over the last two to three years, and it may be that there has been too much bank support and that market forces have not been allowed to prevail to their fullest extent. The net result of this will be a weaker manufacturing industry and not just the agricultural machinery industry but all sectors of engineering.

An indication that there are too many suppliers of any one product is very apparent from table 3. Only a few product examples are shown, but the same problem exists across most of the spectrum.

Low volume manufacture in an over supplied market means low profitability and low investment in new product development. It is very difficult to break out of this vicious circle and it takes bold, imaginative and often risky decisions.

A major dilemma is that, generally speaking, the smaller company can only keep one product, of any degree of sophistication, fully developed, so as to play a leading role in that particular marketing area.

And yet it is unlikely that the one product can in itself generate enough sales to support the whole business.

In order to get this extra turnover, the smaller company could well consider manufacturing products under licence, importation of compatible products, or linking on some basis with another company.

The first course of action is not so easy as might be thought, whilst the second is much easier and far more profitable. Joining forces in some way depends on the aspirations of the owners, many of whom are naturally jealous of their independent status. However, some of this independence may have to be sacrificed if they are to survive — and survival must be the first priority of any company management.

A study of the accounts of 29 companies with sales of between one and seventeen million pounds in 1980/81, showed that of the eighteen who were manufacturers, twelve lost money; of the eleven who were importers only one lost money. There are of course a number of medium sized UK manufacturers who are extremely successful and profitable without any support from imported additions. Names that spring to mind are Bomford and Evershed, Parmiter, and Dowdeswell.

All three have a very high investment in manufacturing equipment, including the introduction of computer controlled robots, so that their products can be made so as to be competitive both at home and overseas. Both Bomford and Parmiters have developed particularly strong export markets, whilst Dowdeswell — whose strength has been to identify the need for a product not met by any other manufacturer at the time — has a good export relationship through Ransomes.

Unfortunately, manufacturing industry is not seen as an area in which a great deal of money can be made. The money lenders and brokers put engineering low on their list of recommendations for investment.

In recent years, entrepreneurial enthusiasm has looked at the service industries as the best bet for the return on invested capital.

However, it is becoming increasingly understood that we have to generate wealth before we can spend it, and a number of organisations, including the Department of Industry, the National Institute of Agricultural Engineering, and the Agricultural Engineers Association recognise that major concerted efforts have to be made if we are to have any success in regenerating the inventiveness and enthusiasm of those involved in the management of our industry.

In recent years, the National Institute of Agricultural Engineering has become more commercially orientated towards supporting the industry with practical research and development. The Agricultural Engineers Association now recognises that part of its role is to encourage manufacturing activity.

The present government knows that we must have a competitive manufacturing sector if we are to be a major economic force in the world.

Through the agency of the Department of Industry, funds are available to manufacturing companies in support of research, design, development, prototype building, and evaluation, as well as by way of investment grants and tax allowances. Currently, more Department of Industry money is available, per employee, in agricultural machinery rather than the motor industry. These opportunities are available to the smaller company and should be taken. I believe, however, that the company should assess the viability of any project on the basis of assistance not being available, because if these financial props are subsequently withdrawn, you must be able to remain standing on your own two feet.

The Department of Industry

Table 3 Analysis of total UK market of certain implements in terms of market share and numbers of manufacturers of home produced and imported products

Product	*Total no sold in UK (home produced & import)*	*No of UK manufactured units sold*	*No of UK manufacturers*	*No of imported machines sold*	*No of imported machine manufacturers*	*Market share, %*	
						Home produced	*Imports*
Drills (all drills other than spacing drills)							
1982	2864		5				
1981	2430	982	4	1448	12	40.5	59.5
1980	2300	929	4	1371	12	40	60
Disc harrows							
1982	1257						
1981	1633	1069	7	564	13	65	35
1980	1916	1265	7	651	13	66	34
Ploughs							
1982	4167						
1981	4180	2097	3	2083	11	51	49
1980	4457	1752	3	2705	11	39	61
Tractor mounted hydraulic loaders							
1982	4350	3000	7	1350	12	69	31
1981	3609	2409	7	1200	11	66	34
1980	4054	2884	6	1170	9	71	29

recognises this and have the criteria of "additionality" when assessing any proposals. This means that the financial support must be rewarded by extra activity and results. They are very keen to encourage import substitution. However, there is surprisingly little emphasis on exports from the Department of Industry. They might perhaps think that export encouragement is the responsibility of the Department of Trade through its Export Department, which largely it is.

However, for a company to develop a product, and the Department of Industry to support that development when the product does not have a real export potential, is to court disaster, as it is only repeating the errors of the past by ignoring that the UK market is only 3% of Europe's total and even less of the world as a whole. I believe that financial aid from government to individual companies must be linked to a good measure of export endeavour and success.

To my mind, exports are the cornerstone of a company's success, as can be seen by studying our continental competitors.

Over the past decades, we have ignored this and are now paying the dreadful penalty.

It was a politician who said that "exporting is fun". It proves that he had never done any. Whilst exporting does have its rewards, it is extremely demanding, often frustrating and always expensive. The best aid any exporter can have is a competitive product — competitive in novelty as well as price. Many smaller companies feel that exporting is fraught with so many difficulties that they are best out of it. But there is no particular mystique — it needs a definite commitment by senior management who must be actively involved and a detailed, painstaking and logical approach to whatever follows.

For the smaller company there are often specialist export houses who can represent you in a particular market. A good company will really understand the markets and be prepared to make long term investment. Many export companies are affiliated to the banks and the employment of one of this type of company can be very beneficial in market areas where funding is a difficulty.

Small companies could consider joining together to present a concerted export effort, particularly where product ranges are compatible. This does need a very positive commitment by each party and one company really has to take control of the project.

In our own case, we have been able to make a great impact in West Africa by adding certain products from two English and one American company to our range, all the products being painted in our colours and under our name. In my own company, AC Bamlett Limited, we have followed a number of different approaches to increase our turnover from £250,000 in 1971 to £4,000,000 today.

In many respects, our problems were typical of those facing so many within our industry. For over a hundred years, the Company had been highly successful as a market leader in the manufacture and sale of grass mowers of the reciprocating knife type. This product became obsolete in a very short space of time, following the introduction of rotary grass cutting technology. Whilst attempts were made to up-date the product in the latter 1960s, the prototypes were not based on sufficiently advanced technology and the project failed.

In the late sixties, the company extended its range very quickly but with relatively simple machines, many of which were close copies of existing products on the market.

This diversification was not totally successful because of lack of originality in the products and in 1970/71 the company reached the stage of bankrupcy without actually going over the edge.

The owners of the company at that stage decided to close the business, but a management buy-out prevented this and gave the basis for a resurrection of what is one of the industries oldest established companies.

It was necessary at that time to generate extra turnover very quickly in order to get some cash flowing again, and opportunities presented themselves for importation of the pneumatic fertiliser spreaders from Sweden and the four wheel drive tractors from Italy.

This approach led to a very good cash flow and good profits. The tractor business has subsequently (1980) been sold so that we can concentrate more on our manufacturing activity and whilst our imports had reached 90% of our sales, this has now been reduced to about 50%.

For a time in the early seventies we virtually ceased to manufacture anything at Thirsk because at the time of the buy-out funds were not available to buy the main factory or any of the plant and machinery. Over this period our own products were made for us by other people, including Bamfords and Russells.

In 1975 it was felt that we had reached a stage where it was possible to re-enter manufacture but we needed to extend our product range. The original factory at Thirsk was re-purchased and we also bought the assets of Knight Farm Machines which included some plant and machinery and some products.

The Knight business was moved to Thirsk and we brought back in house the sub-contracting.

More recent attempts to obtain a licence from the market leader met with a re-buff. An attempt to leapfrog mower development with a linear cutting technique proved a very costly failure and highlighted the problems that face all companies who really have insufficient resources to conduct their own research and development.

We were always faced with the problem of lack of resources to develop and produce a more sophisticated product and when the opportunity presented itself to buy the assets of the seed drill business from Barfords, this was seen to be the golden opportunity.

This purchase, from British Leyland, was made in 1979 and enabled us to immediately enter the market place as a major force and led to the substitution of some of our imported drills from Sweden.

Seed drill manufacture is now our major item. The designs have been very much up-dated in line with current requirements and many of you will have heard of our success with the recent Direct Till system which is making good impact in what has been called the Direct Drill Market.

An important factor in our recent success has resulted from a very conscious decision to employ well qualified people. In 1977 we attracted two graduates from the National College with good success and, overall, now 10% of our total work force are of graduate standard.

Conclusion

So, does the smaller company have a future in our industry? The answer must be "Yes" — but it must be remembered that whilst small may be beautiful, it is also vulnerable.

As we have seen, the market is very overcrowded and profitability low.

The aim must be to identify a niche in the market and become a real specialist in a more sophisticated product.

Choose a product with a definite export potential.

Plan for growth, growth in the development of the product, growth in the expertise of management, growth in financial resources.

Take plenty of advice, — we don't necessarily have to use it but the objective view of one business from an outsider can be a breath of fresh air when we are too close to our problems.

Watch out when company growth has to take the larger steps — this is the dangerous time when we tend to overestimate the potential and underestimate the resources required to see the expansion safely through.

As we grow, we must consider linking with others of like minds, perhaps in product development and particularly in export marketing.

The smaller company usually has the advantages of human energy and enthusiasm, flexibility and product knowledge. We must use these advantages to overcome the disadvantages of lack of resources and lack of muscle in the market place.

Acknowledgement

Agricultural Engineers Association for statistical information and comment.

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SCOTEC Higher Certificate in Agricultural Engineering

J A Pascal

IN the Autumn of 1983, SCOTEC (Scottish Technical Education Council) launched its new Higher Certificate in Agricultural Engineering, designated course 700.

The aim of this course is to provide the agricultural engineer with managerial and technical skills. These will enable him to develop his technical abilities to a higher level, undertake supervisory or managerial roles in industry, respond to new technical developments and changing circumstances within the industry.

Entry to the course will be from those who have already successfully completed the Scottish Technical Education Council Certificate course in agricultural engineering, or its equivalent Technical Education Council Certificate course in England and Wales, and to have passed 'O' grade Mathematics at band A, B or C. Final acceptance for the course is at the discretion of the College Principal concerned.

The recommended period of study is 980 hours, but the Scottish Technical Education Council emphasises that this period is quoted for guidance only and places no restriction on the mode of attendance, whether day release, block release or full time.

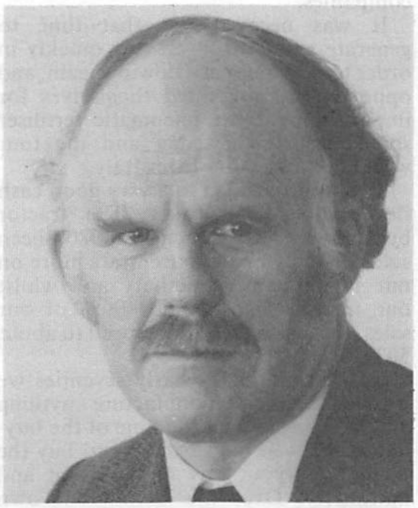
The Higher Certificate will be awarded to a candidate who obtains a pass grade (grade 7 in SCOTEC terminology) or better in each of the following:

- Advanced Engineering Practice
- Business Organisation and Related Studies
- Electronics and Hydraulics

and also any three of the following five subjects:

- Engineering Science
- Field Engineering
- Installation of Fixed Equipment

Jim Pascal is Head of the Cultivations and Liaison Section at the Scottish Institute of Agricultural Engineering. He is Chairman of the Scottish Technical Education Council Sub-Committee on Agricultural Engineering, as well as being Secretary of the Scottish Branch and Deputy Chairman of the Editorial Panel in the Institution of Agricultural Engineers.



- Mechanisation
- Organisation and Management.

From the foregoing, it can be seen that there are three examinable "core" subjects which all candidates take plus a further five from which a student selects three. In addition to these subjects examined through SCOTEC, there is one additional "core" or compulsory subject of Science and Mathematics which is "College" assessed. Moreover, some of the assessments above include more than one subject identified separately in the syllabus, viz Business Organisation, Related Studies, Electronics and Hydraulics are all separate. It is the policy of the Scottish Technical Education Council that 10% of a course should consist of general studies, hence the inclusion of the subject of Related Studies.

The aims of each syllabus are given below together with the method of assessment.

Advanced Engineering Practice This gives the student an in-depth knowledge and the ability to make decisions regarding installation, repair and servicing procedures on diesel engines and their ancillaries, the various types of tractor, crop drying and environmental control equipment, pumps and irrigation equipment, as well as an in-depth knowledge of materials including aspects of erosion and corrosion, electronic monitoring, metrology and advanced technical drawing. Candidates will be assessed by means of a 3 hour written examination.

Business Organisation This includes basic information related to the management, organisation and administration of an agricultural dealer's business. It provides the ability, with experience, to contribute to the organisation and management of the workshop and to give an understanding of the market available to a company and meet the requirements of that market for the continuing prosperity of the company. Candidates will be assessed through a written project, which will include material from related studies.

Related Studies This subject will include methods of information retrieval, the use of libraries, communication and communication aids. Instruction and practical experience will be provided on interviewing and on writing reports. Studies of the work environment and computer literacy are also further aims of the course. A comprehensive course on first aid is included. Assessment is by means of the project mentioned for the previous subject.

Electronics and Hydraulics This introduces the student to basic components of electronics and associated test equipment and gives an awareness of the use of such components in circuit applications used in agriculture. It also provides skills and knowledge to undertake work associated with hydraulic systems. Candidates will be assessed by means of a 3 hour written examination.

Science and Mathematics This provides a knowledge of calculations and statistics that will enable the student to carry out tasks in research, design, production, sales and servicing and gives an overall grounding in general science, especially in those areas not covered to the necessary depth in the agricultural engineering technician course.

Engineering Science This subject is intended to provide additional knowledge to students who intend to undertake the design, development

and/or testing of agricultural machinery. Mechanics, thermodynamics, soil mechanics, tractor power, tractor testing and engineering properties of materials are included in the syllabus.
Field Engineering The aim is to provide the knowledge and ability to carry out surveying, levelling, site preparation and construction of small civil engineering projects, land drainage and irrigation.
Installation of Fixed Equipment This subject gives the knowledge and skill necessary for the layout planning and installation of fixed equipment in farm buildings.
Mechanisation This provides the knowledge required for the planning of suitable systems and the selection of equipment.
Organisation and Management This gives the trainee managerial staff an understanding of the business environment, finance, organisation structure, personnel policy and computer operation and theory.

Assessment of each of the optional subjects will be by means of a $2\frac{1}{2}$ hour written examination.

The first course on this syllabus opened at Elmwood College, Cupar, on 5 September 1983. Those who were involved with the production of the course intend it to fill a gap in the training of the higher technicians and junior managers. It is envisaged that after suitable experience, successful students will find employment in the middle management, including sales, of dealers and manufacturers, and also as higher grade technicians, involved in the design and development of machinery, working in both the public and private sectors.

As many people have worked hard to bring this course to fruition, it is perhaps invidious to mention anyone by name, nevertheless, two names cannot avoid such mention. Firstly, the late George Mouat who chaired the Agricultural Engineering Sub-Committee during most of the time spent in preparing the course, and secondly, Bob Stewart, Head of the Agricultural Engineering Dept, at Elmwood College, a member of the Committee who must take most of the credit for launching the course at Elmwood.

The Centaur tractor

B M D Wills

Agricultural mechanisation in the Developing World

THE shortage of food, common in many parts of the world today, will become progressively greater as populations grow, unless there is a substantial increase in food production. More intensive cropping and an increase in the area of land being cropped is one way in which an immediate increase in food production could result. In order to achieve this, however, there must be an increase in effort to produce the increase in yield. There must be a higher level of power input in crop production.

The peasant farmer is by far the most important source of food production in the developing world. Unfortunately, his manual power output is strictly limited to as little as 0.075kW. If this power level can be augmented by the use of mechanical power, it should be possible to raise food production dramatically. The peasant farmer can best be helped by a simple mechanised system which he can understand and manage himself. There is a very real need, therefore, for a relatively cheap unsophisticated tractor of about 7 to 9 kW designed to suit local requirements. A realistic selling price could be achieved by means of a simple layout based on mechanical components already mass produced for other sections of industry. Such a machine, with matching implements, would be immediately useful and manageable in the context of the small farm. The cost of a unit of this type could be substantially reduced if designed to allow for home based fabrication of the less complex elements of the machine and implements.

A system of mechanised agriculture introduced in this way, to a large extent, will be able to grow naturally from within a community and create its own infrastructure of local supporting services. The Centaur tractor has resulted from an attempt to provide a power unit of the type described above.

A series of design projects for the undergraduate course in Agricultural Engineering resulted in the fabrication and assembly of the equipment by the students. Dr Brian Wills who supervised this project, is Senior Lecturer at the Department of Agricultural Engineering, University of Newcastle upon Tyne.

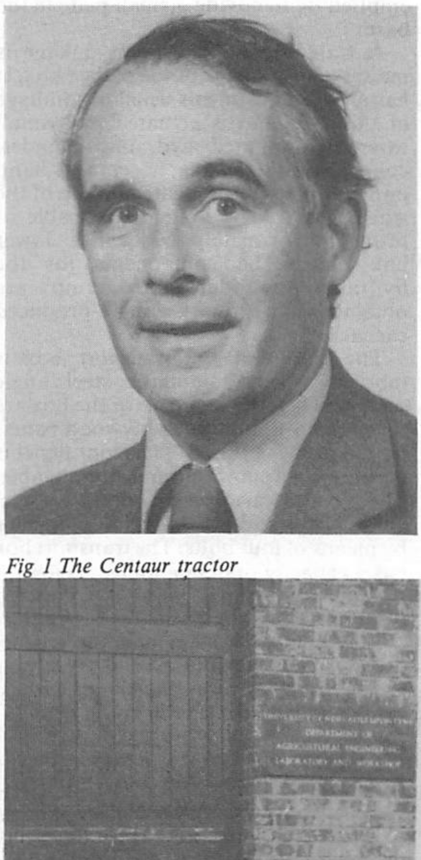


Fig 1 The Centaur tractor

The Centaur tractor

Design

The Centaur tractor is designed around a welded steel chassis made from standard channel section (fig 1). The chassis can be easily fabricated by means of simple cutting, welding and drilling operations. The drawbar is welded directly to the chassis whereas the engine, gearbox, axles, ballast box and transport box are all bolted to the chassis and are readily removable.

The engine used is a 9.3 kW air cooled single cylinder diesel. Although the initial cost of a diesel engine is higher than that of a petrol engine of comparable power, the diesel engine has a much greater life expectancy. It is also more rugged and

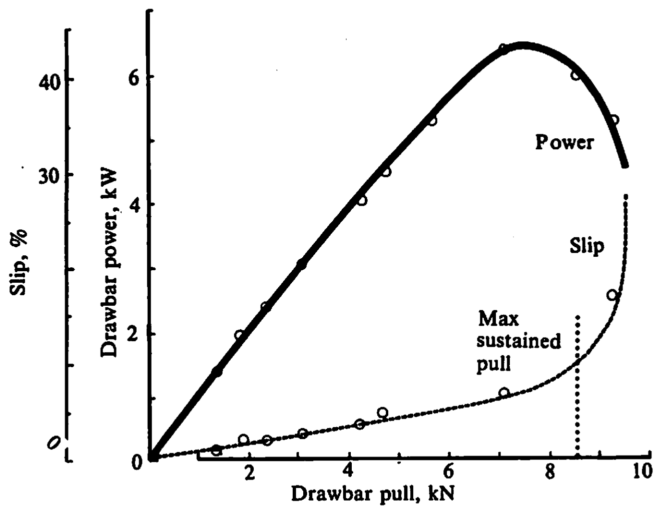


Fig 2 Tractive performance on concrete in first gear, with full ballast, engine speed 2000 rev/min and rear tyre pressure of 1.03 bar

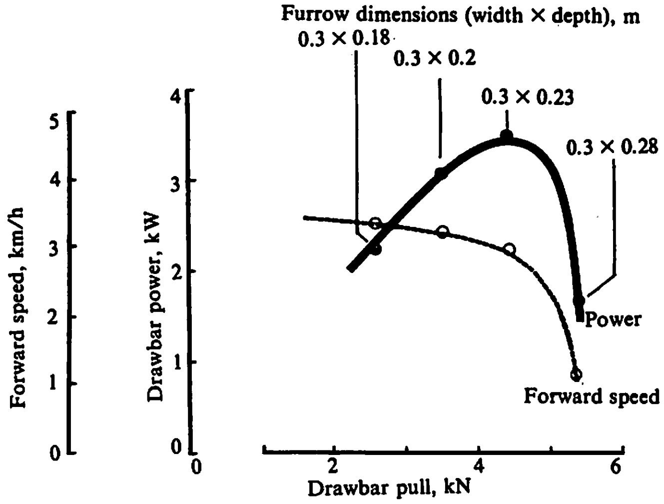


Fig 3 Typical ploughing performance in first gear with a single furrow plough on stubble on a sticky clay loam, using full ballast, engine speed 2000 rev/min and rear tyre pressure of 1.03 bar

easier to maintain and is well suited to a machine of this type. The engine is started by means of a starting handle which extends to the back of the tractor through the ballast box. A hand throttle for speed control is mounted on the ballast box to the side of the engine.

Power is transmitted from the engine to the gearbox by means of a vee-belt drive with a 1.7:1 speed reduction. A spring-loaded jockey pulley, on a swinging arm, tensions the belt drive and acts as a foot operated clutch. The drive pulley on the engine output shaft can also be conveniently used as a power take off pulley. The gearbox has three forward speeds and one reverse speed. First gear provides a high torque for cultivation work, whereas third gear will normally be used for transport. Second gear provides an intermediate speed and torque output which is suitable for rowcrop work. The gearbox transmits power directly to the differential and back axle through a flexible drive coupling. The back axle is equipped with two, lever operated, internal expanding, drum brakes. These are pedal operated, either independently or locked together. A food operated parking brake is also provided.

Steering is effected by means of a recirculating ball steering box connected to the linkage on the centre pivoted front axle by means of a single drag link. The rear wheels on the tractor are used with 9.5/9-24 tyres to maximise traction. The front wheels have 6.00-16 tyres.

It should be noted that the engine, drive pulleys, gearbox, drive coupling, rear axle, steering assembly, front axle and wheels are all components that are already being mass-produced in large quantities for dumpers and similar industrial machines.

The ballast box is fabricated from standard steel angle section welded into a frame. This steel sheet is welded into the sides and base of the frame to box it in. The box is securely bolted to the chassis and is completed by an extended, removable top which also forms a seat and wheel guards. By filling the ballast box with sand or earth, up to approximately 270 kg can be added cheaply and directly to the rear axle to give greater traction. The box can be emptied by removing a small plate in the base.

A Category I, three-point linkage is mounted at the back of the ballast box. It has all the adjustments usual to a linkage of this type and is actuated by a small externally-mounted hydraulic cylinder, connected by flexible hose to a hand pump and reservoir located on top of the wheel guard. The system is capable of lifting approximately 160 kg at the lower link ends. The components for the hydraulic cylinder and pump are obtained from a low-cost, mass-produced car jack.

The frame of the transport box is fabricated from standard steel angle section. The sides and base of the box are made from 12 mm thick plywood panels bolted into the frame. The front panel is mounted in a subframe and is removable. The box is located on the chassis by steel guide plates and is held securely in place by means of four bolts. The transport box has a capacity of 0.3 m^3 and a maximum payload of 450 kg.

Other accessories, such as an engine-driven lighting system and an engine-driven hydraulic system could easily be added to the basic machine with a proportionate increase in cost.

Performance

Slip-pull tests carried out with a fully ballasted tractor, on a flat concrete surface, show that the tractor is capable of developing a maximum sustained pull of 8 kN (fig 2). The test results also indicate that the tractor is capable of a maximum sustained power output of 6.45 kW at the drawbar.

Field tests were also carried out with a single furrow mouldboard plough with a depth wheel. The weight of the plough was 79.7 kg. The tests were carried out on stubble, on sticky clay loam in first gear. The tractor was made to plough at a constant furrow width of 0.3 m and at various depths and its performance measured as shown in the figure. It can be seen that a 0.3 m x 0.23 m furrow could be ploughed quite comfortably at around maximum drawbar (fig 3). A greater furrow depth was, in fact, ploughed and a drawbar pull of 5.1 kN was obtained but at a reduced power output and forward speed. The tractor handled well during ploughing and showed no instability or steering problems. The engine and transmission are seen to be well matched to provide the correct combination of drawbar pull and forward speed required for successful cultivation. The manually operated hydraulic system handled the plough very successfully.

The third forward gear of the tractor gives a maximum road speed of 16.1 km/h. The capacity of the transport box, together with the road speed makes the tractor a useful vehicle for transport. The second forward gear is useful for movement in confined spaces and should also prove to be useful in rowcrop work.

Further development

A prototype machine has satisfied all design requirements and in limited field trials has performed remarkably well. Further rigorous field testing will be required overseas before the machine is ready for manufacture.

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The filtration of air in livestock buildings

G A Carpenter

Why dust occurs

THE high concentrations of dust frequently encountered inside livestock buildings are an inevitable result of the high stocking densities used in intensive systems of husbandry. The situation is aggravated by the relatively low ventilation rates to conserve metabolic heat of the stock for the maintenance of optimum environmental temperatures.

Concentrations of dust are thus highest in cold weather (which means most nights as well as in winter). They are increased by activity of stock and stockman at times of feeding or stock weighing and movement. For growing stock, dust concentrations increase with age and are also influenced by the dustiness of the feed. The dust concentration varies in space and time and deposited dust re-suspended frequently by air currents.

Constituents of dust

Sources of dust are mostly organic, for example skin and feathers, feed, litter and dried faeces. Particle size of suspended dust ranges from 0.1 to 10 μ m. On average, one particle in six, mostly large particles in the range 3 to 10μm, has a live bacterium attached to it. Other particles have viruses or fungal spores attached. Particles that have living micro-organisms attached to them are called viable particles. Viable and non-viable particles can be counted in numbers per m^3 of air either as a total or in different

size ranges. Gravimetric concentration of dust is usually given as mg per m^3 and can be 10 to 80 times greater in animal houses than that out of doors.

Possible effects of dust

Dust may affect the health and performance of livestock in four ways: as a physical irritant of the respiratory tract, as a carrier of toxic chemicals and odours, as a carrier of pathogenic micro-organisms and as a carrier of commensal, non-pathogenic bacteria. Dust may also affect the health of the stockman as for both livestock and humans, the range of particle sizes that is potentially damaging to lungs is 0.5 to 7μm which corresponds to that in suspension in livestock buildings. Although the threshold limited value for inert mineral dust is 10 mg/m^3, there is no overall value for organic dust as its nature is so variable.

The purpose of removing dust

Removal of dust in relation to intensive livestock buildings is usually achieved by use of dry air filters, this method being chosen because of ease of maintenance and low capital cost. Four reasons exist for removing dust in connection with intensive buildings:

1. to prevent infection of special disease free herds or flocks, by sometimes filtering the air entering the building;
2. to reduce nuisance from odours and dust around the building or reduce the chances of cross-infection to livestock in nearby buildings, by sometimes filtering the air leaving the building;
3. to prevent heat recovery or heating and cooling equipment from being fouled by dust accumulation;
4. to reduce nuisance and hazards from dust inside the livestock building itself, only by filtration of internally recirculated air because the dust is practically all generated in the building.

Work at the National Institute of Agricultural Engineering on filtration is concerned with item 4.

Design of an internal air filter

The filter unit is located entirely inside the building and is independent of the ventilation system (fig 1). The unit consists of a suction box (usually floor standing) to which the filter material is attached usually as a flat vertical surface of an area to give a face velocity of about 0.75 m/s. Dust collects on this surface and is removed with a vacuum cleaner. Cleaned air is directed into a discharge duct which is normally overhead with a permeable lower surface. The capacity of the fan in the filter unit is usually made the same order as that of the main ventilating fan. The overhead duct is located above and as near to the stock as possible so that the clean air flows downwards towards the stock. This air

George Carpenter is in Farm Buildings Division of the National Institute of Agricultural Engineering and is the livestock environment subject specialist.

This item was prepared for the British Society for Research in Agricultural Engineering Association Members' Day on Engineering for Livestock Production at the National Institute of Agricultural Engineering on 11 May 1983.

Fig 1 Experimental dust filter (NIAE photo)

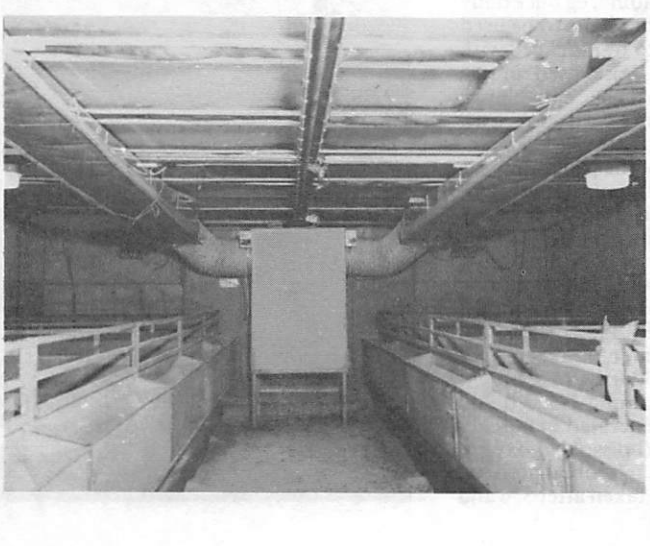
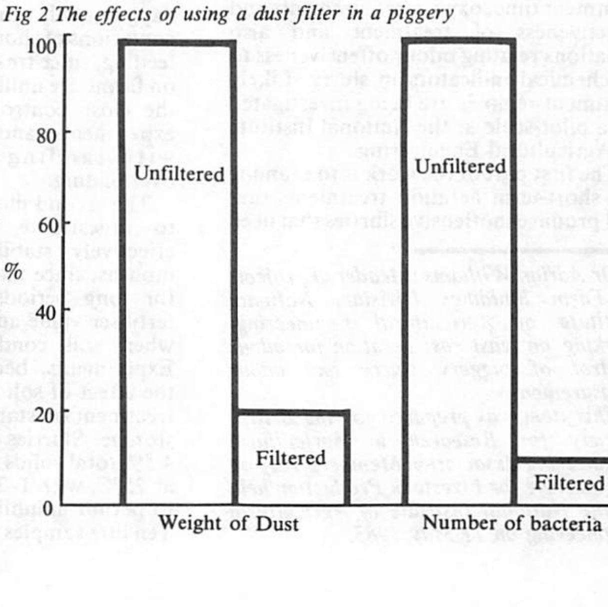


Fig 2 The effects of using a dust filter in a piggery



does not cause a draught because it is discharged at a low speed (0.3 m/s) and as it is recirculated it is at the same temperature as the air in the room.

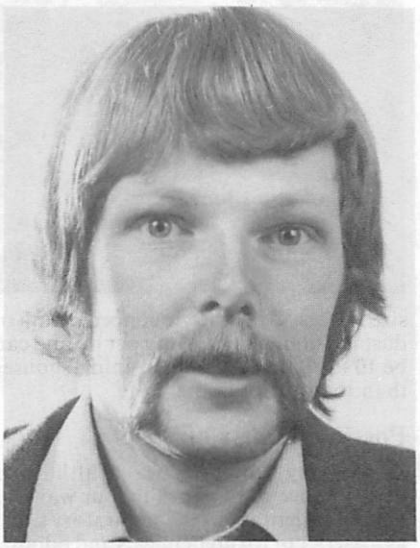
The effects of internal air filtration

The effects on livestock are likely to depend partly on the disease status of the stock. Those with respiratory diseases such as pneumonia and rhinitis are more likely to benefit than those that are entirely free of disease.

Experiments with veal calves have shown that filtration reduces the incidence and severity of virus pneumonia. Experiments with early-weaned pigs in a rhinitis-infected herd have shown a 25% greater growth rate between 3 and 7 weeks of age (fig 2). Further experiments are needed to establish the cost effectiveness of air filtration.

Control of piggery slurry odours by aerobic treatment

A G Williams



THE number of complaints received by local authorities caused by offensive agricultural odours has increased from 660, between 1960 and 1970, to 3828, between April 1980 and March 1981. Of the complaints, 2107 concerned pig units and 1679 of these concerned the collection, storage and land-spreading of excreta, thus making these activities the largest cause of odour complaints. Today, most pigs are kept on slatted floors and their excreta are collected as slurries. Slurry smells more offensive than manure from straw-bedded pigs, which composts and so loses much of its smell. The majority of complaints about pig units are thus directed against piggery slurry and in most of the odour control work at the National Institute of Agricultural Engineering pig slurry is used.

Aerobic biological treatment is an effective way of eliminating the offensive odours from slurry but most farm treatment systems designed to control odour are over-designed, and so are expensive to run. The objectives of this project is to provide design criteria for the selection of the most economical aeration regime(s) to control odours from piggery slurry.

Work in the Microbiogical Department of the West of Scotland Agricultural College has shown, on a laboratory scale, that continuous flow treatment systems make better use of the air supplied than batch treatments. The West of Scotland Agricultural College have also produced equations linking treatment time, oxygen requirements and effectiveness of treatment and also equations relating odour offensiveness to biochemical indicators in slurry. Likely treatment regimes are being investigated on a pilot-scale at the National Institute of Agricultural Engineering.

The first part of the work is to examine the short-term aeration treatments that will produce inoffensive slurries that need to be spread within a few days of treatment because they will not be stable for long. In these 12 trials, two 500 litre reactors treat separated piggery slurry, with a residence time of 1, 2, 3 or 4 days, temperature controlled at 35°C and with low, medium or high aeration rates (fig 1). The separated slurry is fed every one or two hours (true continuous feeding is impractical on this scale) and equal quantities of treated effluent are removed at the same intervals. Samples are periodically removed, and stored without further aeration and their stability assessed.

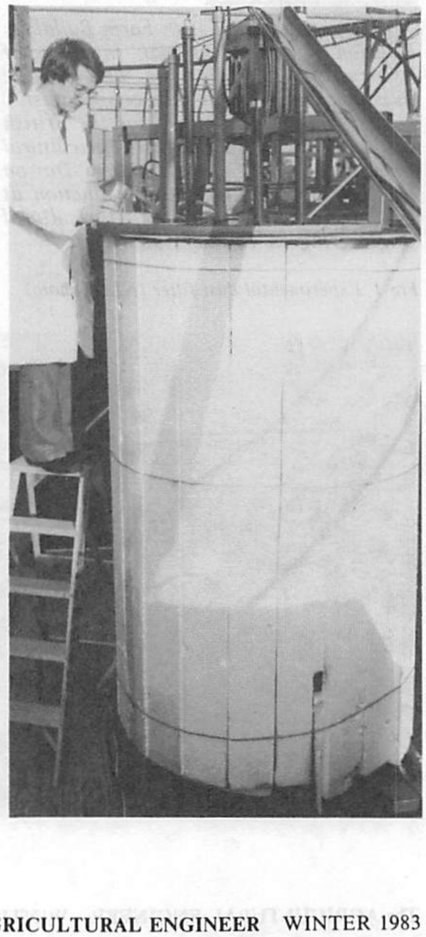
The treatment systems needing least oxygen will then be tested under conditions of shock loading, eg once daily feeding, since treatment plants to be used on farms are unlikely to be managed with the close control of those used in the experiments and must be capable of withstanding some abuse and overloading.

The second phase of the programme is to investigate treatments that will effectively stabilise slurries for 6–12 months, since many farmers store slurry for long periods to obtain maximum fertiliser value and avoid land-spreading when soil conditions are unsuitable. Experiments, begun in 1982, examined the effect of solids content and extent of treatment on stability during subsequent storage. Slurries containing 1.5, 3.0 and 4.5% total solids were aerated in batches at 25°C, with 1–2 mg/l dissolved oxygen to permit uninhibited microbial activity. Ten litre samples were taken after 3, 6 and 9 days and stored for 36 days at 10°C without further aeration. Volatile fatty acids were monitored as indicators of odour offensiveness.

Preliminary results indicate that dilute slurries are inherently more stable than concentrated ones that have received the same amount of oxygen and have been aerated for the same length of time. Slurry containing 3% total solids remained stable for 10 days after 3 days treatment, but extending the treatment to 6 and 9 days produced slurries that were stable for 60 and 100 days, respectively.

From the result of these experiments various treatment processes will be assessed. The main options are either prolonged aeration before storage, which is simple in concept but probably more expensive, or a short period of aeration followed by a period of controlled anaerobic storage with the second short period of aeration prior to spreading. This system is more complex to manage but it could be cheaper to run.

Fig 1 Pilot scale aeration vessel (NIAE photo)



Dr Adrian Williams is leader of projects in Farm Buildings Division, National Institute of Agricultural Engineering, working on least cost aeration for odour control of piggery slurry and odour measurement.

This item was prepared for the British Society for Research in Agricultural Engineering Association Members' Day on Engineering for Livestock Production held at the National Institute of Agricultural Engineering on 11 May 1983.

The Agricultural Engineer

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1 Preparation of the text

The manuscript should be typewritten with double spacing and wide margins on one side of A4 paper. The original and one copy are required for editing and printing.

2 Length of paper

Papers for presentation at Conferences *must not* exceed 5,000 words in length.
Papers for direct publication must not exceed 10,000 words in length.

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All main and sub headings should be in lower case typescript except for the first letter of the first word, proper nouns and generic names. The main headings should be typed as a separate line of text with an extra line space above and below and without any underlining. Sub headings should precede the first line of the paragraph to which they relate.

4 Format

Underlining should be used only to denote italics for parts of the text and for scientific names of pests, plants, etc.

There should be no stop at the end of any heading or caption unless the last word is an abbreviation of which the stop is a part.
For example:
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5 Title page

The title page should include: the title, and the name(s) of the author(s), their affiliation(s) and passport photograph(s).

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The manuscript should include a summary of not more than 400 words.

7 Abbreviation of units

The SI system should be used throughout the text as well as in the tables and figures, British Standard PD5686 (1972). The plural of all abbreviations is the same as the singular, eg kg (not kgs). The solidus is used to denote "per" except in the case of more than two units when negative indices are used, eg m/s and $W\ s^{-1}t^{-1}$.

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Symbols should be defined in the text where they first appear. Where many symbols are used in the paper, they should be listed in a "key to symbols".

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Drawings should be on tracing paper, artboard or faintly lined graph paper in black ink. Use stencils, flexicurves or Letraset in preference to freehand lines. Lines finer than 0.4 mm do not give adequate quality of reproduction.

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