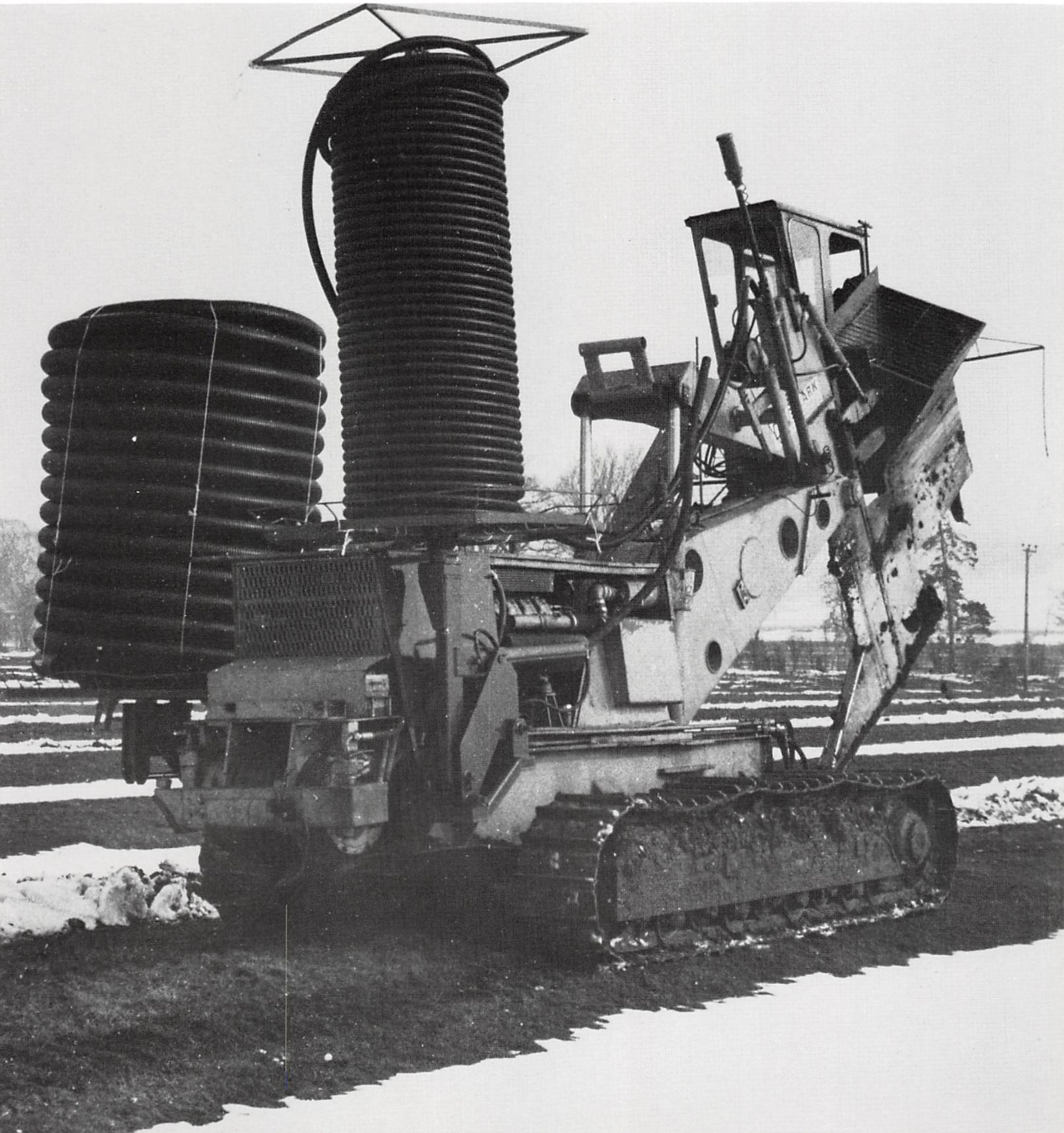
THE AGRICULTURAL ENGINEER

JOURNAL and Proceedings of the INSTITUTION of AGRICULTURAL ENGINEERS

Volume 38 SPRING 1983 No 1 (ISSN 0308-5732)



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ISSN 0308–5732

Volume 38 **SPRING 1983** **No 1**

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

Tel: Silsoe 61096

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

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Contents

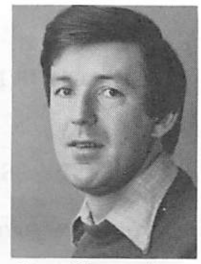
Three categories of paper appear in the Journal:-

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

Front cover: Bruff TGS trenchless drainage machine fitted for "Superkoil".

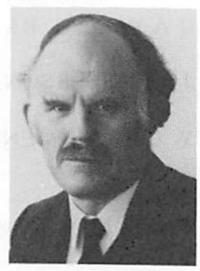
Energy requirements for the reduction of clod populations during potato land preparation

J A Pascal, A Langley, B W Sheppard, A J Hamilton

Sandy Hamilton *Barry Sheppard*

Allan Langley *Jim Pascal*

Abstract

ONE spring tine harrow and four pto-driven cultivators were used on seven replicated trials over a period of six years to assess their performance with regard to soil comminution and energy consumption for the preparation of potato land following conventional ploughing. Each machine was selected as being typically representative of similar designs currently marketed in the UK.

A presentation technique was evolved to separate machine and soil effects when evaluating the results of the work. The importance of a clod free ridge for ease of harvesting was stressed.

Results indicated that one pass of the draught implement did not provide enough soil comminution. All the pto-driven machines generally provided satisfactory tilths with the exception of an 'L' bladed Rotavator. However, under stony conditions both the Vicon reciprocating harrow and the Roterra cultivator ha/d blockage problems.

The Vicon reciprocating harrow had the lowest energy consumption but the stratification of the tilth from this machine appeared to cause changes in the tuber size distribution of the crop.

1 Introduction

WHEN herbicides are used for weed control and inter-row cultivations are omitted in potato husbandry techniques, secondary cultivations for the preparation of the seed bed assume greater significance because the remaining clod population in the ridges persists to a greater extent from planting through to harvest. Thereby, an increased work load is imposed upon the harvester separating machinery and output is reduced (Jarvis 1972, Pascal and Langley 1971). However, the degree of soil comminution required for maximum crop yield is more difficult to quantify (Shotton 1971) and additional clod reduction may not be of direct benefit towards increasing yield.

The advent of stone windrowing techniques has not reduced the need to avoid clods at planting time, since excessive clod numbers result in the creation of a large quantity of separated material for burial. Difficulties can then occur with following crop operations (Witney 1977).

Jim Pascal, Barry Sheppard and Sandy Hamilton are in the Cultivations and Liaison Section of the Scottish Institute of Agricultural Engineering, Penicuik, Midlothian EH26 0PG; Allan Langley is a Mechanisation Adviser with the East of Scotland College of Agriculture, West Mains Road, Edinburgh EH9 3JG. (Refereed paper)

Since the oil crisis of the early 1970s there has been a dramatic increase in the price of crude oil together with concern over the long term availability of this non-renewable resource. Hence, there is a need for the agricultural industry to reduce the use of such energy either by using alternative sources or using oil based products more efficiently (David 1978, Stout *et al* 1977, Pascal 1980).

An assessment of energy input for growing the potato crop gives a total of 31709 MJ/ha, of this 17% or 5439 MJ/ha is required for cultivations and harvesting (White 1975). This percentage represents the second largest input (the greatest input being artificial nitrogen representing 41% of total energy).

Nevertheless, the physical conditions required for growing and harvesting the crop make it necessary to plough and cultivate to get good soil comminution to sufficient depth. A survey conducted by the PMB (PMB 1976) shows that all potato land is ploughed and a wide range of secondary cultivations are then carried out. This survey states that in Scotland, 64% of secondary cultivations are carried out by rotary cultivation, as compared with 40% in England and Wales. An earlier survey and measurement of energy use carried out in Scotland (Pascal 1975) shows the popularity of the rotary cultivator, but also indicates that implements such as reciprocating harrows, Cambridge rolls, heavy rigid tine cultivators, light rigid tine harrows and spring tine harrows are used. However, it is apparent that, in medium to heavy soils where fine soil comminution is required, pto driven cultivators give a superior performance in relation to the degree of soil comminution achieved (Pascal 1975).

It was therefore decided to undertake a number of trials in a range of medium to heavy soils to assess the following: clod yield at planting and at harvest; potato yield, and the energy consumption of a variety of secondary cultivation implements particularly pto powered machines. It was realised that soil variation caused by parameters such as the contents of clay, organic matter and moisture; degree of compaction etc, might have as much effect on tilth production as machine design (Campbell 1982). Therefore, the trials were laid out and results presented in such a manner that soil effects could be separated from machine variation effects.

2 Description of machines

Each machine was selected to represent a typical example of all the commercial machines of a similar design available in the UK market and the results reflect on the type of cultivating mechanism rather than on a particular make or model.

(a) Vicon reciprocating harrow (fig 1)
This was a mounted pto-driven machine fitted with two reciprocating bars, each bar having oval section vertical tines mounted along it. The pto was operated

Fig 1 Vicon reciprocating harrow

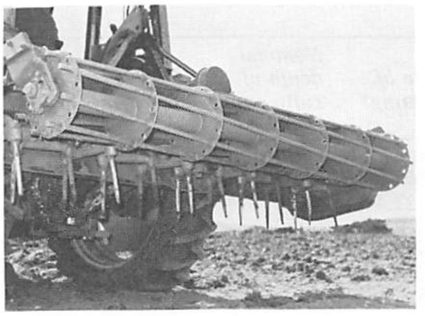


Fig 2 Lely Roterra vertical shafted rotary cultivator

Fig 3 Howard Rotavator

Fig 4 Howard Rotaspike

to give 540 cycles per minute. The machine had a working width of 2.8 m.

(b) Lely Roterra vertical shafted rotary cultivator (fig 2)
This was a mounted pto-driven machine fitted with ten rotating heads, the rotational axis being vertical. Each head had two tines of circular cross-section set diametrically opposite each other. The machine was fitted with a crumbler roller and had a working width of 2.5 m. However in fields 2 and 3, a different but similarly equipped machine, with a working width of 3.5 m, was used.

(c) Howard Rotavator (fig 3)
This was a mounted pto-driven machine with a horizontal rotor having 'L' shaped blades fitted to it. Three different machines were used having working widths of 1.6 m (field 1), 1.8 m (fields 2, 3) and 2.0 m (fields 4, 5, 6, 7).

(d) Howard Rotaspike (fig 4)
This was similar to machine (c) except that the 'L' blades were replaced with circular spike tines. Three different machines were used, having working widths of 2.2 m (field 1), 2.8 m (field 3) and 2.0 m (fields 4, 5, 6).

(e) Triple K spring tine harrow (fig 5)
This was a mounted machine fitted with spring tines and having two adjustable depth wheels on the frame. Three different machines were used having working widths of 2.8 m (field 1), 2.6 m (field 2), and 3.0 m (field 7).

3 Trial procedure

3.1 Machine performance assessment

Before work started, all machines were used on an area outwith the plots to obtain optimum settings and similar working depths. Detailed measurements of soil comminution, due to a change in the ratio of rotor speed (or other relevant parameter of an implement) to forward speed, has not been included. Other work (Pascal and Sheppard 1978-80) has shown machine setting to be of less importance than inherent implement design so far as the degree of soil comminution is concerned. Therefore, machine setting was considered to be satisfactory if evaluated qualitatively before the recorded work was undertaken. Depth measurements of the worked soil were made by taking the adjacent unworked soil as a datum since all machines did not leave tilled soil with the same bulk density.

Spot rates of work are quoted. These are derived from the implement width and forward speed of the tractor. In practice, rates of work would be less than these due to overlaps on successive passes with the implement and due to time taken for headland turns. However, as the rate of work figure is used for energy determination from tractor power consumption, the higher and less variable figure has been used to avoid bias in comparing the energy consumption per unit area of different machines.

Tractor power measurements were undertaken with a thermocouple inserted in the exhaust manifold of the tractor to measure gas temperature. The equipment had been previously calibrated with a pto dynamometer (Pascal and Brown 1974). Two identical 55 kW tractors were used throughout these trials.

3.2 Soil, clod and potato sampling

A representative sample of soil was taken from the experimental area and subjected to analysis by standard methods (Soane and Campbell 1978). After carrying out these full sampling procedures in fields 1 and 2, it became apparent that the results were of little value in determining when and what cultivation procedures should be adopted to provide the finest tilth. In fact, the farmers own qualitative assessment of soil conditions was a much better guide. Therefore, in subsequent fields, only that part of the test appertaining to soil texture (USDA classification) was carried out.

Clod size distribution measurements were undertaken from the full depth of the ridge, immediately after planting and again immediately before harvest, although at field 7 wet weather prevented samples from being taken at harvest. The method of sampling following planting was by hand digging a 0.75 m length of ridge, taking all the material to the level of the furrow bottom and hand riddling over 30, 45 and 55 mm square mesh sieves. Four samples were taken in each plot. Clod and potato yields at harvest

Fig 5 Triple 'K' spring tine harrow

were taken from the centre rows of each plot using the NIAE ridge analyser machine (Patterson and Sharp 1969) which gave agitation similar to that achieved by a potato harvester. Normally four samples were taken from each plot, the length of ridge sampled varying in each condition according to the clod content but it was usually between 6 and 10 metres. This machine provided the same size grading as the hand riddles, but the degree of agitation was greater. Previous work (Pascal 1975), comparing the two sampling methods for clod content estimation, indicated that comparative differences between cultivation treatments were maintained, although absolute levels of clod content were reduced by sampling with the ridge analyser.

4 Field conditions

4.1 Soil and crop description

Details of the soil series and texture (USDA classification) are given in table 1, together with date of planting, potato cultivar and depth of cultivation.

4.2 Cultivation and planting

The common Scottish practice of cultivating no more than a few passes in front of the planter was followed. Hence, planting dates given in table 1 are also representative of cultivation dates. The work was carried out directly on to cereal stubble ploughed during the previous winter. The potato cultivars were planted in 0.76 m drills. It was intended that weed control should be carried out with herbicide spray and no inter-row cultivations were to be carried out. However, at fields 1, 4 and 7 some inter-row work was done after planting for a number of commercial reasons (the growing of these commercial crops was outwith the control of the authors). Nevertheless, such treatments were not severe and the bulk of the ridge was not touched. Field 5 (silt loam) was stone windrowed after cultivation which effectively nullified the differences between treatments at harvest (fig 7).

Table 1 Soil and crop description

Field no	*Soil series*	*Soil texture (USDA classification)*	*Date of planting**	*Nominal depth of cultivation, mm*	*Potato cultivar*
1	Macmerry	Loam	1-5.5.75	170	Maris Peer
2	Winton	Clay loam	20.4.76	160	Pentland Crown
3	Humbie	Clay loam	25-27.4.77	180	Pentland Hawk
4	Humbie	Sandy clay loam	3-4.5.78	170	Pentland Hawk
5+	Whitsome	Silt loam	10-14.5.79	165	Pentland Hawk
6	Stirling	Silty clay loam	25.4.80	170	Desiree
7	Pressmennan and Hobkirk	Sandy clay loam	5.5.80	175	Dunbar Rover

**Secondary cultivations were carried out on the same day as planting.*
+Field stone windrowed between cultivation and planting.

5 Results and discussion

5.1 Soil comminution

The results of the clod population measured at planting and again at harvest are given in fig 6 and 7, respectively. Clod populations are given by the vertical axis measuring from the plane surface enclosed by the horizontal scales showing energy consumption on the left hand side and soil texture (USDA classification) on the right. Each vertical column represents a clod yield from a given machine on a specific soil within an energy consumption range. Since fig 6 represents seven fields under differing soil states at planting, the results are not comparable between all the individual columns. However, one would expect that soils with the highest clay fraction would require the highest energy input for clod breakdown and that the cloddiest soils after cultivations in general would have the lowest energy input. Hence, column height should decrease towards the rear of each figure. In fact no such trend exists which suggests that other previously mentioned parameters associated with soils and/or the design of the implements used are affecting the results.

The reduction in mean height of the columns between planting and harvest is not a true reflection of a reduction in clod yield during this period. In fact, it is a measure of the two different methods used to assess clod population at these periods. The use of a modified harvester for the harvest assessment compared with hand digging at planting, had a more severe effect on clods and therefore caused more soil comminution by the time samples were taken from the picking table. The harvest method of sampling was the more realistic of the two assessments so far as measuring the clod populations that would be sorted by a harvester. Nevertheless previous work had shown a distinct correlation between the two methods (Pascal 1975).

In order to separate the interaction of soil effects and machine design on the results given in fig 6 and 7 the following procedure was adopted to provide ratios of machine performance compared to the best achieved, viz:

$$\text{specific implement performance in clod reduction} = \frac{1}{n}\sum_{i=1}^{n}\frac{x_i}{L_i} \qquad (1)$$

where x_i = clod yield from a specific implement,
L_i = lowest clod yield from any implement at a particular field
n = no of fields used for experimentation.

The results were then depicted in a bar chart, fig 8, whereby the shortest bar represents the lowest ratio and hence the best performance (ie the lowest comparative yield of clod). Figure 8 includes clod yields obtained immediately before planting and again at harvest. No statistical analysis of two pass systems was made for the reason given below fig 8 (excluding the Triple K). Therefore little inference should be given to a difference between one and two pass treatments.

The Triple K was used as a two pass implement only because none of the farmers would accept a single pass treatment from it.

The differences in comparative clod breakdown of any one machine between planting and harvest were probably a reflection of the hardness of the clods left at planting and weather conditions

Fig 6 Relationship between energy consumption, clod yield and soil texture at planting

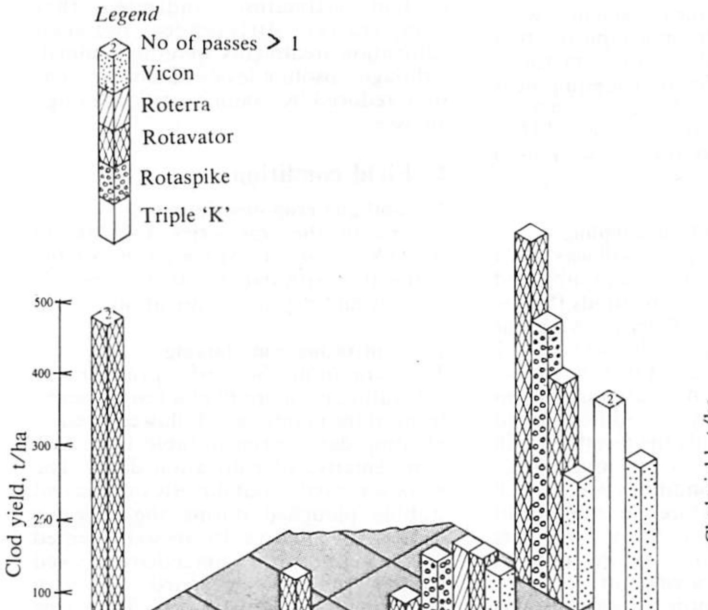
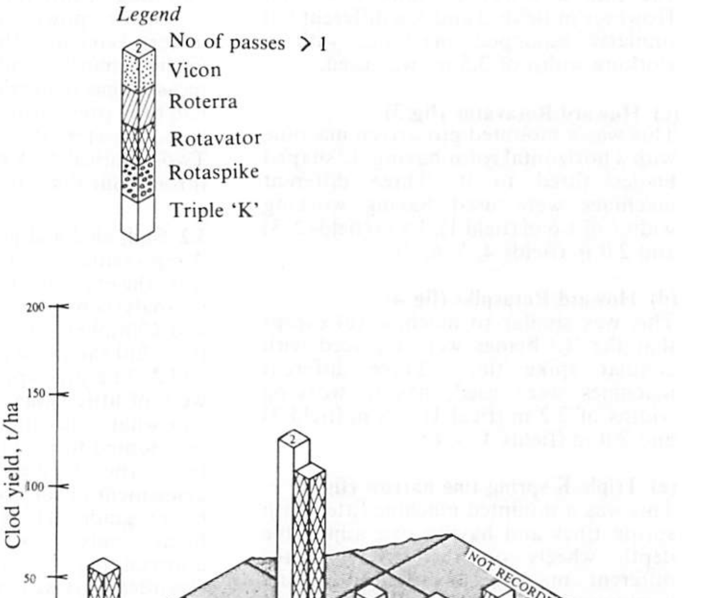


Fig 7 Relationship between energy consumption, clod yield and soil texture at harvest



during the growing season. In addition to certain other previously mentioned treatments between planting and harvest, the greater agitation of the sampling device at harvest broke down more of the softer clods.

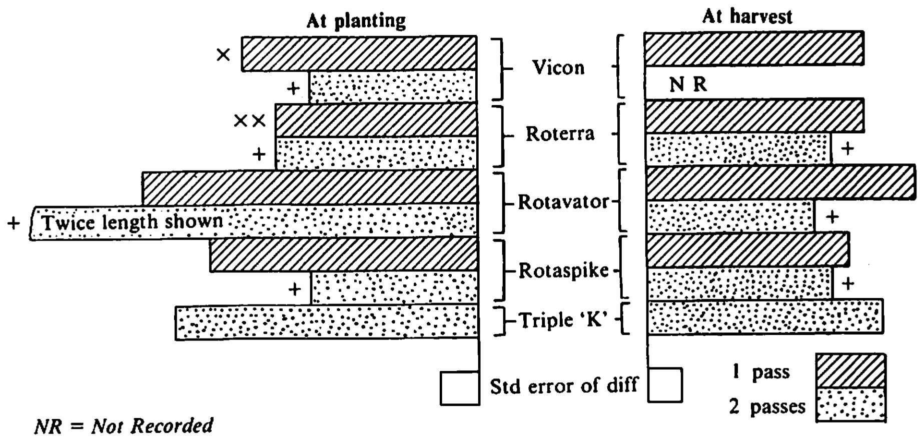
The Vicon, Roterra and Rotaspike all provided satisfactory tilths with a one pass treatment, the Vicon being significantly better than the Rotavator and the Roterra being significantly better than both the Rotavator and Triple K (fig 8). However, in field 6, the Vicon had to be withdrawn from the trial because it was unable to provide sufficient soil comminution to satisfy the farmer. In the same field, the Rotaspike provided as much soil comminution in one pass as the Roterra produced in two passes. A greater effect could be obtained from the second pass with the Rotavator and Rotaspike than with the other two machines. It was also noted that the former tended to bury stones while the other machines, particularly the Vicon, dragged them to the surface causing blockage problems.

5.2 Potato yields

Average total yield (>30mm) of potatoes from all fields, given in table 2, was not significantly different between any of the plots cultivated by the different implements. This was also true of all individual fields except field 6 where there was a visual difference between plots cultivated by the Rotavator and the other treatments. After cultivations with this machine, crop growth was retarded and haulm height did not match the other treatments until late in the season. This resulted in a significant drop in yield from this treatment at that particular field. It appeared that the very cloddy seed bed left by the Rotavator was the primary cause of the slow crop growth.

The apparent higher yields obtained from two pass treatments are the result of only one treatment being recorded for this type of operation (except for the Triple K). At fields 1 and 2, low yields were recorded which effectively reduced the mean yield of one pass treatments.

A significant increase in the smallest potato size grade and nearly a significant decrease in the largest size grade ($P \leqslant 0.05$) was obtained with the Vicon. Qualitative examination of the cultivated soil



NR = Not Recorded
NB Shortest bar represents lowest clod content
× *Significantly less than 1 pass of the Rotavator ($P \leqslant 0.05$)*
×× *Significantly less than 1 pass of the Rotavator ($P \leqslant 0.01$) and 2 passes of the Triple K ($P \leqslant 0.05$)*
\+ *Not included in statistical analysis as these treatments were used at sites 1 and 6 only*

Fig 8 Proportional clod content in the potato ridge

following the work of this implement showed that unbroken clod was left in the surface, while fine soil was buried. With other implements such as the Rotavator, the reverse situation occurred. Unless there is a satisfactory soil mixing action during the following ridging treatment, any surface clod is moved to the centre of the ridge. This has the same effect as reducing the cross-sectional area of the ridge resulting in more of the crop grading out in the smaller sizes (Kouwenhoven and van Ouwerkerk 1978).

5.3 Energy consumption

Energy consumption was also evaluated by a similar procedure in order to compare the various implements, viz:

energy consumption of a specific implement

$$= \frac{1}{n} \sum_{i=1}^{n} \frac{Y_i}{E_i} \qquad (2)$$

where Y_i = energy consumption from a specific implement

E_i = lowest energy consumption from any implement at a particular field

n = number of fields used for experimentation.

These results were then depicted on a bar chart, fig 9, whereby the shortest bar represents the lowest energy consumption. Again, two passes were not evaluated statistically for the reasons mentioned previously with the exception of the Triple K which was used at certain fields with other one pass treatments.

Energy consumption was lowest with the Vicon used as a one pass treatment, significantly so compared with certain other treatments as shown in fig 9. The Rotavator had a high energy requirement, even greater as a one pass treatment than the Triple K as a two pass treatment possibly due to the much higher forward speed of the latter implement.

Table 2 Potato yields

Implement	*No of passes*	*Tuber yield, t/ha*			
		>55 mm	*45–55 mm*	*30–45 mm*	*Σ(>30 mm ø)*
Vicon	One	11.0	13.4	15.4*	35.5
Vicon	Two	NR	NR	NR	NR
Roterra	One	12.6	13.9	14.1	35.9
Roterra	Two	16.1+	24.2+	12.3+	52.6+
Rotavator	One	12.2	12.8	13.2	34.0
Rotavator	Two	9.2+	23.0+	15.5+	47.7+
Rotaspike	One	13.4	12.7	14.2	35.6
Rotaspike	Two	9.4+	27.8+	15.7+	52.9+
Triple K	Two	12.6	13.1	14.1	34.2
SED	—	1.14	1.04	0.36	0.96

NR Not recorded
ø *Total yield means are drawn from six fields for one pass treatments, whereas individual grade means are from four fields. Therefore total grade means = total mean yield.*
\+ *Excluded from statistical analysis as yields represent a single two pass treatment only at field 6.*
* *Significantly greater than all other one pass treatments and two passes of the Triple K ($P \leqslant 0.01$)*

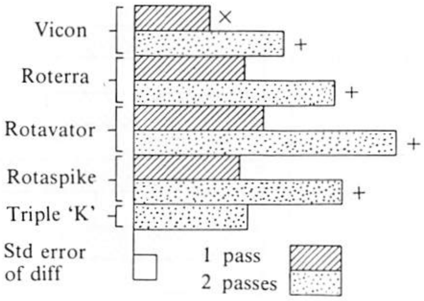
6 Conclusions

(a) The differences in soil conditions have as much, if not more, effect on the degree of soil comminution achieved than the variation in the design of the implements.

(b) The design of implements is, none-the-less, important in the degree of soil comminution obtained. Of the pto machines, the Rotavator is the least effective, whereas the Vicon reciprocating harrow, the Roterra and the Rotaspike are generally satisfactory.

(c) In stony conditions, the Rotavator and the Rotaspike tend to bury stones and unbroken clod while other machines have the reverse effect, particularly the Vicon. Both the Roterra and Vicon have blockages when large stones are present.

(d) In general, potato yields are unaffected by the design of cultivator used. There is some statistical evidence to show that the Vicon stratifies the tilth in such a manner that the following ridge contains sufficient clods to cause the crop to consist of more potatoes in the smaller size grades.



NB Shortest bar represents lowest energy requirements

× *Significantly less than 1 pass of the Rotavator (P ⩽ 0.01) and 2 passes of the Triple K (P ⩽ 0.05)*

\+ *Not included in statistical analysis as these treatments were used at sites 1 and 6 only*

Fig 9 Proportional energy requirements for special cultivation implements

(e) The Vicon has the lowest energy consumption of all the machines, whereas that of the Rotavator is relatively high. The Triple K harrow has a relatively low energy consumption for a two pass treatment.

Acknowledgement

The help and assistance of the following is gratefully acknowledged: Messrs A Bathgate, C Spence, G McClung, J Marshall of the Lothians: J Bryden of Perthshire and R Walker of Berwickshire who provided sites and crops for the trials: Messrs B Dawson of Lely Import Co Ltd, and I Ross of Howard Rotavator Co Ltd, who loaned manufacturers' demonstration machines: C A Glasbey of ARCUS for help with the statistical analysis: R Clark of SIAE (now retired) for analysis of soil samples.

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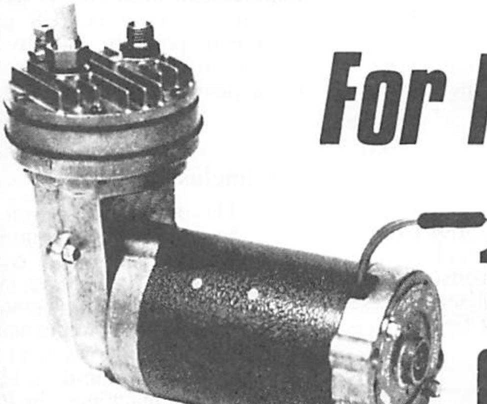

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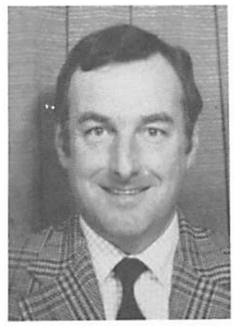
Trenchless drainage in England and Wales



C B Stansfield

Introduction

TRENCHLESS drainage is a 'permanent' drainage system in which a blade or share is pulled through the soil to form a slot at the design depth and grade into which a pipe is fed. It does not include the more 'temporary' drainage such as gravel filled moles, plastics lined moles or zip-up pipe.

Development of trenchless drainage

Interest started in the trenchless drainage technique in the mid 1950s and development took place in several parts of the country. The early National Institute of Agricultural Engineering machine and two winch pulled machines were modifications of the long beam mole plough. At the same time, Dr Ede, working for the Ministry of Agriculture, Fisheries and Food at Cambridge, developed the short beam principle with the roller linkage, the first model being used to lay zip-up pipe.

It was not until the mid 1960s that a crawler machine, the Walton/Critchley, and then winched units became available commercially. In these early days, grading was based on radio control with manual sighting onto a grade board fixed to the rear of the machine; a radio message was sent to tell the machine driver what to do to alter the grade. From that time, a number of both crawler direct pull and winch pulled machines were marketed.

Growth of trenchless drainage

BY 1971, 4% of the underdrainage schemes in England and Wales were carried out by the trenchless method (fig 1), amounting to approximately 3200 hectares. At this time, there were still problems with bad workmanship, mainly due to poor operator training and lack of experience rather than to any fault of the system.

By 1979, there had been a growth to approximately 11% or 10,000 hectares, and it is estimated that 14,000 hectares are now being drained by the trenchless method. The rate of increase is approximately 1000 hectares per year, there being a steady increase in the amount of trenchless work carried out rather than a rapid rise.

Chris Stansfield is with the Land and Water Service of the Agricultural Development and Advisory Service and is based in London. This paper was presented at the inaugural meeting of the Field Engineering Group on 11 October 1982 at the invitation of South East Midlands Branch. (Crown Copyright reserved).

Distribution of work

Statistics from the Ministry of Agriculture, Fisheries and Food (fig 2) show the distribution in England and Wales. On a regional basis in 1971, there was little work carried out in Wales, South West, South East, Eastern or West Midland Regions, with most work being carried out in the East Midland, Yorks/Lancs and Northern Regions.

By 1979, the amount of trenchless work had increased markedly in Northern, Yorks/Lancs and East Midland Regions with a major increase in West Midland Region and Wales, but very little work being carried out in the south and east.

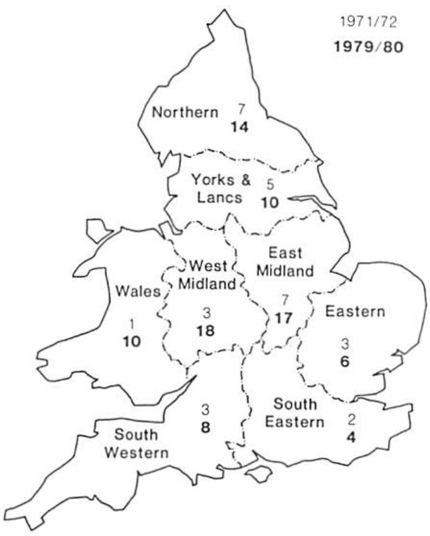


Fig 2 the percentage of normal underdrainage schemes laid by the trenchless method in the Ministry of Agriculture, Fisheries and Food Regions

Length of drains laid

While looking at the distribution of work throughout the country, it is as well to look at the actual length of drains laid on a regional basis (fig 3). East Midland is

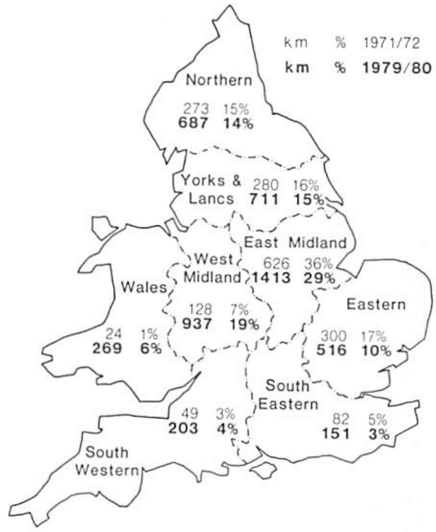


Fig 3 The length of drains laid by the trenchless method in the Ministry of Agriculture, Fisheries and Food Regions

the leader with West Midland, Yorks/Lancs, Northern and Eastern Regions following on behind. The amount of work carried out in the Ministry of Agriculture, Fisheries and Food Divisions is interesting, with most trenchless drainage being carried out in Northampton Division closely followed by Durham, Worcester and finally Cardiff (fig 4).

Reasons for the growth

Plastics pipes

The trenchless drainage technique was originally developed to lay zip-up pipe and in-situ concrete, although in the early days many clay pipes were laid. The bulk of trenchless schemes used plastics pipes which were suited to the technique, and fig 5 shows how, in the early days, the growth in plastics pipe usage and the increase in the amount of trenchless drainage were related. It was not until the mid 1970s that other factors — such as

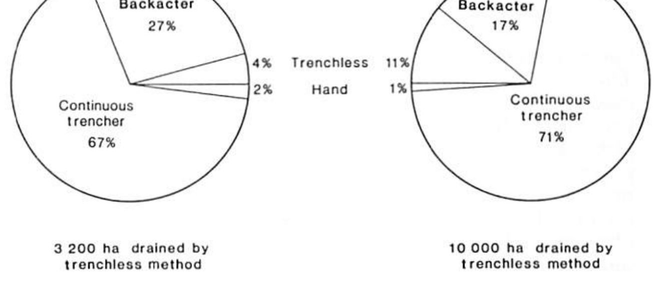


Fig 1 Method of installing underdrainage schemes

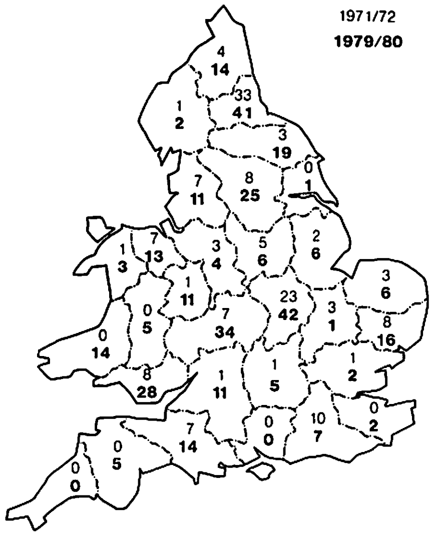


Fig 4 The percentage of normal underdrainage schemes laid by the trenchless method in the Ministry of Agriculture, Fisheries and Food Divisions

haulage, material price, reduced labour costs and convenience — made plastics pipe more attractive that this relationship changed.

Savings on permeable backfill

The slot cut by trenchless machines is in the range of 100-125 mm wide whilst older conventional open trenchers were cutting 175-200mm wide trenches. This meant that the amount of permeable backfill needed for trenchless work could be up to 50% less. As permeable backfill accounts for over half the cost of many schemes, this immediately gave the trenchless method a 25% price advantage.

Trenching machine manufacturers have not been complacent and open trench machines are now available that cut 100-125mm wide trenches. The current savings on permeable backfill can now be quite small, depending on the availability of machinery in a particular location.

Soil damage

The trenchless method, by cutting a slot and pushing the soil aside, does not bring any poor quality subsoil to the surface. The actual relativity between the subsurface and surface layers is not changed. Open trenching, on the other hand, mixes all the soil in the profile, possibly creating problems in unstable subsoils or where stones are present.

In grassland areas, the heave created by trenchless drainage needs to be rolled carefully so that silage and hay making machinery can operate without hindrance.

Speed of work

This is one aspect where trenchless machines can gain. A high power outfit is capable of laying 5000-6000 metres of pipe a day, whereas an equivalent powered open trench machine might only manage about half of this. These figures do not show the whole picture because obviously the size of scheme, layout, outfalls, junctions and soil type will affect the daily output. The average scheme size in England and Wales is only 6.6 ha with the distribution skewed towards the smaller scheme (table 1).

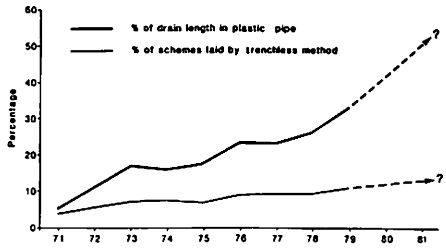


Fig 5 Plastic pipes and trenchless drainage

Table 1 Percentage distribution of the average size of drainage schemes

Scheme size ha	*Percentage distribution*
2	17
2–4	26
4–8	32.5
8–16	24.3
16–32	0.2
32–64	0.1

What is significant, however, is that in the larger scheme size over 8 ha (fig 6), the trenchless method is most favoured. In the 8–16 ha range, the crawler trenchless installation method predominates.

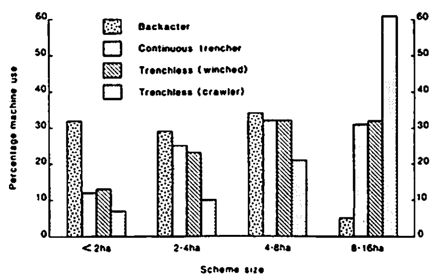


Fig 6 Machine use and job size

Wear and tear

This again is another area where the trenchless method shows favourably as there are no moving parts in contact with the soil. Trenchless machines are particularly useful in stoney soils and soils with thin stone layers or very compact horizons; the only maintenance needed is to keep the point and the blade hard faced. In such situations, wear on cutting blades and chains of conventional trenches can be excessive and, therefore, expensive. Trenchless drain laying is now gaining in popularity in the difficult conditions found with the drainage of restored open cast coal sites.

A further important aspect of wear and tear is machine reliability for, with less moving parts, there are fewer breakdowns which in turn means less downtime. This should reduce contractors overheads and permit them to offer more competitive prices to the farmer customers.

Grading

Most trenchless units tend to use the accurate laser grading control, thereby increasing speed of work and reducing operator fatigue. An essential feature is that the laser system must be set properly and needs frequent checking.

Good contractors

One of the reasons for trenchless drainage being more popular in some localities than others is because of good local contractors. Once a contractor is experienced with the use of the trenchless technique and provides a first class job, with good materials and good operators, the word soon gets around.

What about the future?

The trenchless drainage technique is well proven with advantages in terms of speed, maintenance and lower costs. There are still some problems on the horizon.

1 Tradition

Farmers on the whole are "conservative" in their approach. They are suspicious of what they cannot see and quite rightly so. Contractors must set out their method of working to do a good, thorough job. The farmer is the customer — the person who pays the bill. He has a right to know what is going on and to be shown exactly what is happening.

2 Soil damage

Problems have arisen with soil damage from two counts: surface damage when drainage is carried out in unsuitable conditions; and subsoil smearing especially in fine textured soils with water table control problems.

3 Grading

This can only be as accurate as the laser system and much depends upon accurate setting up. Older machines do not have rapid response hydraulic systems and so that grading accuracy, even with good laser systems, can be suspect.

4 Existing systems

In upland areas, especially with clay soils, there are still many problems associated with old systems and the tradition of connecting them to the new scheme. Even though permeable backfill is used, old stone drains and even more modern systems can create blow outs which are troublesome to the farmer and costly for the contractor to put right. The answer is for a more thorough site investigation to be carried out prior to drain installation and reference to old record plans if these are available.

5 Headlands

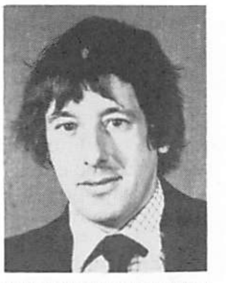
Headlands are always a problem because of the extra traffic. As trenchless drainage units get larger, it becomes impossible for them to lay a drain to within 12-15 metres of the field boundary. Alternatives involve laying headland drains which may not be in the best position for secondary treatments or redesigning machines to mount the engines sideways and reduce overall length.

Conclusions

The trenchless technique is sound and well proven and is a viable alternative to open trench drainage. Indeed in some soils, it may be the only economic method of drainage. The future will see the continued growth of trenchless drainage but there will always be a balance between the various drain laying methods due to site factors, scheme size and customer preferences.

Trenchless drainage tines — soil disturbance, field performance and practical implications

R K Fry



Summary

THE nature of soil disturbance generated by trenchless drainage tines is described. Two simultaneous soil deformation processes are identified and final soil disturbance is shown to depend on the dominant process. The effect of soil disturbance is assessed in terms of local reductions in hydraulic conductivity near the drain, and overall drainage performance. Three soil conditions are identified as most vulnerable to smear and/or compaction in the vicinity of the drain and ways to avoid, reduce, or eliminate problems of reduced hydraulic conductivity are discussed.

Introduction

TRENCHLESS drainage machines are now extensively used in N America, Europe, and the United Kingdom. The operational and cost benefits over other installation methods have led to a rapid growth in this method of sub-surface drainage pipe installation. Some concern has, however, been voiced with regard to possible compaction or smear in the vicinity of the drain in some circumstances, see Naarding (1979), Egglesman (1979) and Olesen (1979). These comparisons of trenched and trenchless drainage installations all pointed to possible problems of high entry resistance for water flow into the pipe in fine textured soils, when using trenchless methods to effect groundwater control drainage.

This paper discusses the nature of soil disturbance caused by trenchless drainage tines and identifies the circumstances where reduced drainage efficiency could arise. The magnitude and overall effect on system performance of local zones of soil damage in the vicinity of the pipe are quantified and ways of avoiding, eliminating or reducing these effects are discussed.

Soil Disturbance

Figure 1 shows a typical range of soil disturbance profiles caused by trenchless drainage machines working at various depths under different soil conditions. Two types of profile are apparent, one where the boundary between loosened and unloosened soil radiates outwards from the tine working depth at an angle of approximately 45°, and the other where the loosened soil zone at depth is greatly reduced and takes the form of a slot.

These disturbance profiles are the final result of two forms of soil deformation which occur simultaneously as narrow tines, such as trenchless drainage implements, move through the soil. The two forms are:—

(i) *lateral deformation* — a continuous, general form of disturbance ahead of the tine, closely associated with horizontal planes, similar to that shown in fig 2, with the soil moving along many slip planes but not necessarily reaching complete failure;

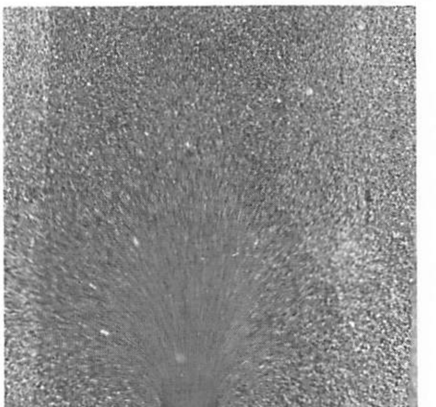
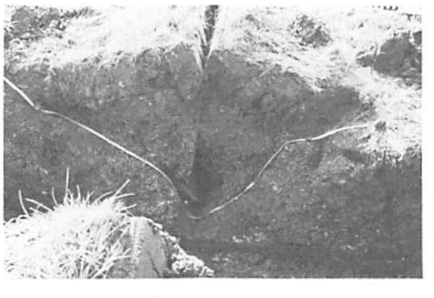
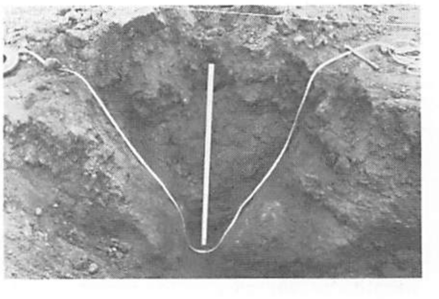


Fig 2 Lateral deformation (after Godwin & Spoor 1977)

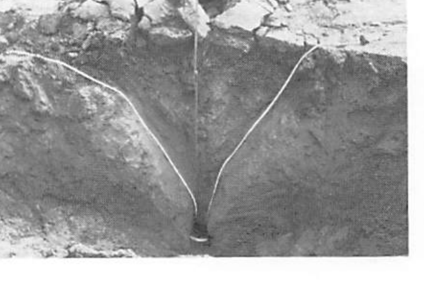
Fig 1 Typical soil disturbance profiles





(a) Clayey, Shallow (above) deep (below)

(b) Sandy, Shallow (above), deep (below)



Bob Fry is a Research Officer at the National College of Agricultural Engineering and is working on Mole Channel Stability, an investigation which is grant aided by the Agricultural Research Council. This paper is based on a talk presented at the inaugural meeting of the Field Engineering Group on 11 October 1982 at the invitation of South East Midlands Branch. *Crown Copyright reserved.*

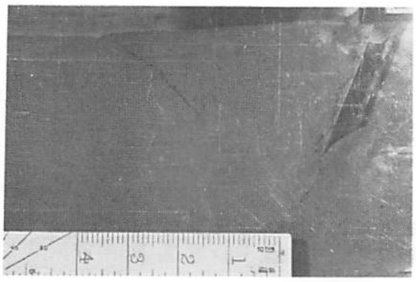


Fig 3 Brittle upward failure (after Godwin 1974)

(ii) *brittle upwards failure* — an intermittent form of disturbance, relatively close to the tine, where soil is brought to complete failure and slips towards the soil surface alng a few well-defined slip planes as shown in fig 3.

The brittle upward failure planes may be generated either beyond or well within the area of soil already strained in a lateral manner, depending on the boundary conditions. With shallow working tines, these failure planes, radiating at a wide angle from working depth, see fig 1(a), are likely to be near the limit of the lateral deformation and hence little residual lateral deformation is likely to remain after the passage of the tine. With deeper working tines, the brittle failure planes tend to occur close to the tine, see fig 1(b), well within the lateral deformation zone and residual deformation may be found beside the drain. There is a tendency, therefore, for the final dominant type of soil disturbance at drain depth to change with increasing depth of working; from brittle upward failure with no residual lateral deformation when shallow, to lateral deformation when deep. The transition from one failure type to the other with increasing working depth tends to be gradual. It is, however, convenient from a practical point of view to recognise a critical transition depth. In this paper, the critical transition depth, or critical depth, is defined as that working depth below which lateral deformation becomes dominant and the total distance between the failure planes generated at depth on either side of the tine, is limited to approximately 1.5 tine widths.

Various soil properties and conditions have been found to influence the critical depth. Critical depths tend to increase with increasing soil density, decreasing moisture content and decreasing soil compressibility. The vertical confining stress exerted by the surface layers on the soil at depth is also a major factor. High surface confining stresses reduce critical depth by increasing the resistance to upward soil movement. Critical depth also tends to increase with increasing tine width but the influence of the soil conditions is usually greatest.

With above-critical-depth type of disturbance, little or no soil disturbance occurs beyond the major failure planes and the soil within them is loosened and displaced upwards. When working below the critical depth, however, compaction or smear may occur in the lateral deformation zone at the side of the tine, in certain soil conditions. Any such compaction or smear could have a significant effect on water entry resistance to the drain and could influence overall drainage performance.

Effect of local reductions in hydraulic conductivity on overall drainage efficiency

Electrical analogue studies of Fry and Spoor (1983) have shown that compaction beneath and smear alongside the drain can increase water table heights in groundwater drainage situations. Smear alongside the drain was found to have a much greater effect than compaction beneath the drain. Compaction beneath the drains alone causes minimal rise in water table providing it is limited to less than two drain diameters in width (fig 4). Any significant smear alongside the pipe when combined with compaction beneath the pipe causes a rapid and undesirable rise in water table as shown in figure 5. Actual field effects may be less than those predicted in figure 5 which represents the case where the hydraulic conductivity in the smeared and compacted zones was reduced to zero. In the field, smear is often discontinuous along the drain run and compaction not so severe.

In drainage situations where perched or surface water problems exist, smear or compaction beneath or alongside the drain have little or no effect on the overall drainage system efficiency. In such circumstances, water flow to the drain is vertically from above and the soil permeability directly above the pipe becomes the limiting factor. No reductions in drainage efficiency will occur when permeable fill, natural or artificial, is placed above the pipe at installation. In the absence of permeable fill, the flow of water to the drain depends on the degree of loosening caused by the tine and on the presence or otherwise of smear and large cracks.

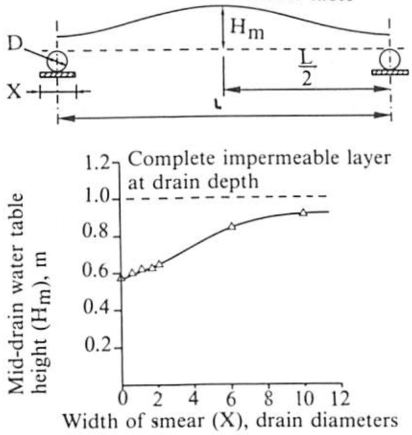
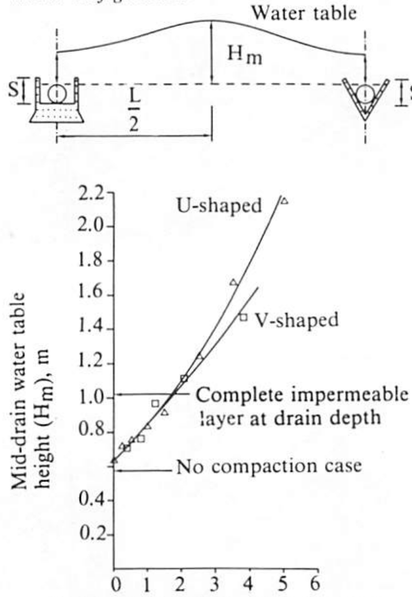


Fig 4 Effect of bottom smear on water table height at mid-drain spacing

Fig 5 Effect of side smear on water table height at mid-drain spacing, for two compaction/-smear configurations



Soil conditions most vulnerable to damage

Soil structural damage, with resulting reduction in hydraulic conductivity, is most likely to occur in the vicinity of the pipe with tines working below the critical depth. This reduction in hydraulic conductivity may be caused by soil compaction, smearing or simply soil shear with no net density change. Field and laboratory observations have identified three soil conditions which can be particularly vulnerable to reductions in hydraulic conductivity.

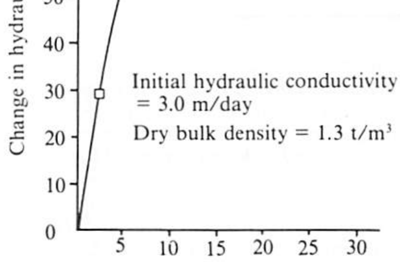
(i) *Unsaturated, low density, single grain or fine structured soils and soils containing large vertical air-filled cracks.* Extensive lateral compaction can occur in such soils.

(ii) *Higher density soils at high degrees of saturation and with appreciable clay contents.* These are particularly susceptible to smear or local reworking.

(iii) *High moisture content, low shear strength, weakly structured, fine textured soils, containing discrete macro-pores* Complete loss of, or reductions in macro-pores can occur in these soils due to extensive shear with little density change.

In low density sandy loam soil, total volume reductions of approximately 5% have been found to distances approaching four tine widths from the tine. Figure 6 shows that this volume

Fig 6 Effect of changes in total soil volume on hydraulic conductivity of a sandy loam soil



reduction is sufficient to reduce the hydraulic conductivity by 50%. In similar tests in fissured soil conditions, soil was displaced laterally by mass flow, often completely filling cracks at a considerable distance from the tine.

Smearing and local reworking in higher density soils is usually confined to bands of 2-10 mm thickness at the tine/soil interface. The thickness of these bands of smear increases as soil shear strength decreases. Typically, the hydraulic conductivity of a dense clay soil could fall from 4.5 to 0.02 mm/day as a result of such smear, rendering the soil virtually impermeable in the vicinity of the pipe. However, removal of this 5-10 mm smeared or reworked zone from the sample returns the hydraulic conductivity to that of the undisturbed soil.

In low density, fine textured soils at or near saturation, compaction is very difficult. Such soils are, however, easy to shear and, when discrete macro-pores are present, these may become distorted, have their continuity disrupted, or completely collapse due to this shearing action. Fig 7 shows the distribution of macro-pores around a pipe cavity resulting from a tine working just below its critical depth, in a 90% saturated silty clay loam soil of 1.1 t/m^3 density. Near the tine/soil interface macro-pores are

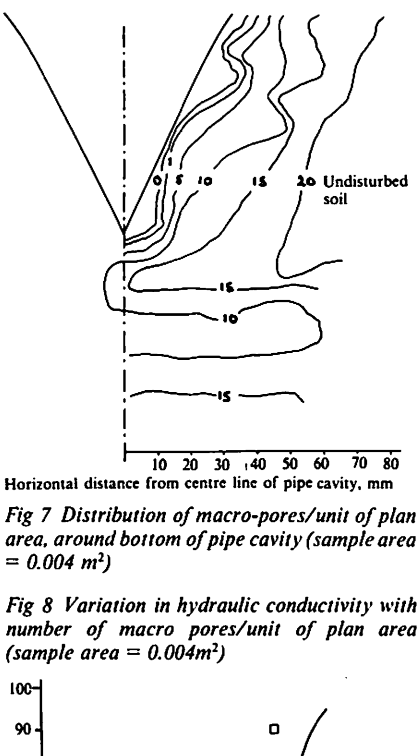
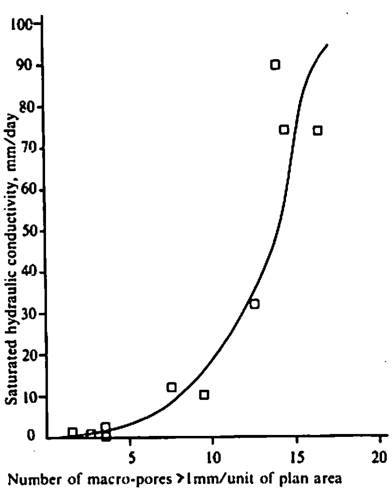


Fig 7 Distribution of macro-pores/unit of plan area, around bottom of pipe cavity (sample area = 0.004 m^2)

Fig 8 Variation in hydraulic conductivity with number of macro pores/unit of plan area (sample area = 0.004m^2)



severely reduced in number and size, and the tine influence extends to approximately one tine width (125-150 mm) either side of the tine. The effect of this loss of macro-pores on hydraulic conductivity can be seen from figure 8. Even a small reduction in the number of discrete macro-pores reduces the hydraulic conductivity substantially. The soil may approach a completely impermeable state near the pipe cavity when macro-pores are reduced to zero.

These examples illustrate the potential severity of the problems which could arise in vulnerable soils as a result of reductions in hydraulic conductivity within the lateral deformation zone, with tines working below critical depth.

Practical Implications

The effect of trenchless pipe installation on drainage system performance is dependent upon the nature of the drainage problem, the type of soil disturbance caused by the tine and the soil conditions at the time of installation.

In groundwater control drainage, water entry to the pipe is largely from the bottom and immediately alongside the tine and in such cases bottom compaction and side smear will reduce the drainage efficiency. In mole drainage, and in surface and perched water areas, water entry is from above the pipe and therefore impedance above the drain has the greatest influence.

The type of soil disturbance generated by the tine is dependent upon soil conditions and working depth. Its effect on drain performance can be conveniently discussed in terms of tine working depth relative to critical depth.

Working above critical depth

The disturbance associated with tines working above their critical depth is unlikely to have any adverse effect on drainage efficiency in either bottom or top water drainage. The loosening and upward displacement of the soil will improve drainage of surface or perched water but reduce mole channel stability.

Working below critical depth

When tines are working below their critical depth, problems may arise in groundwater control due to side smear or compaction near the pipe in some soil conditions. This smear and compaction, however, will not influence drain performance in top water drainage when a permeable backfill provides a vertical connection to the pipe.

For groundwater drainage, the three soil conditions already identified are those on which problems are most likely to arise through reduced permeability near the pipe.

Soils susceptible to smearing are common in many areas and local smeared zones may be virtually impermeable. In high moisture content, low shear strength, clayey soils, smear may be almost continuous but in most other soil conditions smearing will be discontinuous. These dicontinuities, combined with cracking of smear on drying, tend to reduce the severity of the impedance effects.

The occurrence of low density, compressible soils which could be subjected to extensive lateral compaction at depth, tends to be limited to the surface soil layers where below-critical-depth disturbance is unlikely. Where fine textured soils exhibit fissuring to drain depth, they are usually very dry and critical depth is below drain depth. Extensive lateral compaction, however, could occur in moderately dense, unsaturated, coarser textured soils when subjected to very high vertical confining stresses. Vertical confining stresses on soil at depth may be increased by surface compaction, differential drying, or simply increases in drain depth.

Low shear strength soils containing discrete macro-pores tend to be limited mainly to certain fine textured marine sediments. When moisture content is high and macro-pores are not strongly stabilised, reductions in hydraulic conductivity near the pipe are most likely to occur.

Very high water flow resistances can develop above the drain with tines working below critical depth in conditions where no fissures develop along the pipe run. This situation is most likely to occur in low shear strength, weakly structured, fine textured soils when no permeable fill is inserted into the slot opened up by the trenchless tine and can severely affect top water drainage.

The base of the trenchless tine and the tile box will cause compaction or smear beneath the pipe at all working depths. This is, however, only important in groundwater control cases if allowed to exceed two drain diameters in lateral extent.

Possible modifications to installation techniques to minimise problems

The risk of installation problems occurring can be minimised by ensuring that tines work above their critical depths whenever possible, and by limiting the width of compaction beneath the drain. These requirements can often be achieved using standard equipment and techniques in many soil conditions. In conditions where drain depth would be below critical depth, any modification which will shift the critical depth to below the depth of draining will be advantageous.

The critical depth can be lowered by increasing the tine width, or by pre-loosening the soil surface layers to reduce the resistance to upward movement. Care must be taken in using wider tines to ensure that the critical depth is lowered beneath drain depth, otherwise the extent of lateral deformation will be increased with further deleterious effect in vulnerable soil conditions.

Pre-loosening of the upper soil layers to reduce vertical confining stresses may be achieved using either the drainage tine itself or suitably positioned shallower leading tines. These have operational advantages over pre-loosening in a separate pass using the drainage tine.

Where side impedance, from whatever source, is unavoidable it may be possible to reduce or completely eliminate any deleterious effects in the same pass as installing the pipe. Partial removal of the affected smeared zones can alleviate as much as 90-95% of the impedance effect on overall drainage efficiency. The critical area for removal of side impedance is immediately alongside the pipe. This can be achieved, in practice, providing the smeared layers are of limited thickness, using cutting blades attached to the rear of the tile box. The action of these cutters is to fail soil in such a way as to leave undisturbed soil alongside the pipe, improving the hydraulic conductivity.

When soil conditions result in sealing up or closure of the leg slot behind the tine and the use of gravel is uneconomical, soil from the most permeable layers in the profile may be placed in the leg slot to improve the vertical connection to the drain.

Mole channel stability can be improved by reconsolidation of the loosened soil above the drain before moling. This can be easily achieved using the drainage machine or its return journey to roll down the 'heave'.

There is scope for the design of specialist drainage tines to suit specific drainage requirements. Tines could be interchangeable and only one power unit would be required. The use of the Vee-plough (which has no critical depth) in marine sediments in the Netherlands is one example — whilst giving the required soil disturbance, the plough is limited in operating depth and cannot place permeable fill over the drain. In areas where good soil loosening is desired, wider tines combined with shallow leading tines may be preferred. By contrast, the contractor working solely on mole-cum-tile schemes may prefer a narrow tine with steep rake angle to ensure below-critical-depth-disturbance at shallow working depths, thus improving mole channel stability.

Conclusions

Two forms of soil disturbance generated simultaneously by trenchless drainage tines have been identified — brittle upward failure and lateral deformation. When tines operate above critical depth, brittle upward failure dominates and soil is loosened and displaced upwards, little change occuring beyond the major failure planes. Below critical depth, however, lateral deformation is dominant and residual soil deformation may be found alongside the drain following installation. In some soil conditions, reduced hydraulic conductivity can result beneath and alongside the drain as a result of lateral deformation.

In surface, perched water table, or mole drainage situation this side impedance will not affect the drainage efficiency since water entry to the drain is vertically from above. In these situations, the condition of the backfill above the drain has the greatest influence on drainage efficiency.

In groundwater control drainage, water entry to the pipe is mainly from beneath and alongside the drain and water tables are very sensitive to any significant impedance alongside the pipe. Compaction beneath the pipe has little effect, providing it is limited in width to two drain diameters.

Three soil conditions have been identified as being most vulnerable to side impedance problems with tines working below critical depth. These conditions are:

(i) unsaturated, readily compressible soils which may be subjected to extensive lateral compaction;
(ii) soils susceptible to smear or reworking at the soil/tine interface, where soil damage is limited in extent to bands of 2-10 mm;
(iii) fine textured weakly structured, soils of high moisture content containing discrete macro-pores which may be lost or reduced due to soil shearing action.

The most commonly encountered of these soil conditions is that where smearing occurs, the other two classes being less widespread.

Side impedance problems can be avoided if tines operate above critical depth. In many soil conditions, existing equipment and techniques can achieve this. The critical depth can be increased, however, by using wider tines and pre-loosening the upper surface layers to reduce the resistance to upward soil movement.

When side impedance cannot be avoided at installation, it can be removed immediately using suitable cutting blades mounted to the rear of the tile box, provided the lateral extent of the soil damage is small.

In soil conditions where the use of permeable fill is uneconomical, and fissures are not created above the pipe, the soil may 'seal' up behind the tine. The vertical connection for surface or perched water can be maintained under these conditions by placing soil of greater permeability, from the surface layers, into the leg slot.

Mole channel stability is poor when crossing the above-critical-depth soil disturbance of freshly installed laterals. Stability can be greatly improved by reconsolidation of the loosened soil over the drain before moling.

Some problems of trenchless drainage installation may be avoided by the use of tines specifically designed to meet the requirements of the type of drainage being installed.

Trenchless drainage installations can be used confidently in a wide range of soil conditions and drainage situations. In some soil conditions, problems may arise when operating at depth but with care, and in certain cases modification to equipment and/or technique, these problems may be alleviated and often eliminated.

Further details of the studies described in this paper can be found in the references Fry and Spoor (1983) and Spoor and Fry (1983(a)(b)) and in the report to the Agricultural Research Council, reference Number AG63/140.

Acknowledgements

The author wishes to acknowledge the financial support of the Agricultural Research Council, the considerable resources freely loaned by many land drainage contractors and R Ford for his invaluable assistance in field and laboratory. Thanks are also due to Professor G Spoor for his helpful comments and encouragement.

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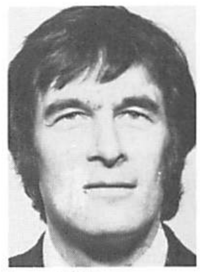
Corrosion and materials degradation in the agricultural industry

A nationwide survey with economic and technological aspects

P Elliott, C M Fowler, J B Johnson and G C Wood



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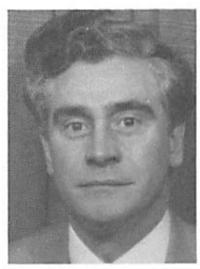

Brian Johnson

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Abstract

RESULTS of this first nationwide pilot survey of corrosion and related problems in the agricultural industry reveal annual direct (first order) corrosion and materials degradation losses of about £180M. The inclusion of approximate estimates for consequential (ie second order) losses and equipment depreciation suggests that total annual losses could be in excess of £500M.

Information relating to all types of farming activity is presented and the findings highlight a degree of unawareness and a lack of understanding of corrosion and control measures. Recommendations include the establishment of an advisory service, probably as an extension of an existing nationwide organisation, the running of short instructional courses, and the need to explore more fully certain findings in this survey to confirm their validity and ensure pertinent action.

1 Introduction

The agricultural industry is one of the largest sectors of British industry, employing approximately 3%* of the total civil working population and 80% of the land area of the UK. The total farm output for 1978 (HMSO 1980) was estimated as £7,064M (3% of the Gross National Product) and over 65% of the Nation's food requirements were supplied, with additional earnings of £3700M from exports. The farm expenditure for the year 1975 (HMSO 1980) was £2794M, of which 13.7% (£383M) was spent on machinery and 6.4% (£179M) on maintenance. The expenditure on machinery rose to £650M for the year 1978 and this figure has no doubt risen since then because of the intense use of farm machinery in Britain, illustrated, for example, by a current total tractor population of 504,000 (HMSO 1980), one of the most densely populated of any agricultural industry in the world.

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Data on corrosion in agriculture are lacking. Many countries have published data on corrosion, but only two have revealed figures for their agricultural industries. In the United States of America, a comprehensive document (US National Bureau of Standards, 1978) details the findings of a team of workers whose task was to estimate the cost of metallic corrosion to all the major industries in the USA. For the year 1975, agriculture sustained a £1170M direct loss due to metallic corrosion, 58% of which could have been saved by using known protection schemes. When indirect losses were considered the corrosion loss figure rose to £2943M, with 49% avoidable. There were very few industries whose corrosion losses exceeded these figures.

The Report of the Committee on Corrosion and Protection (UK) (Hoar 1971) made note of the absence of any information pertaining to the agricultural sector of British industry, stating that insufficient time was available to collect and process the data from such a widely dispersed industry.

It is evident then that the cost of material degradation to the agricultural industry is an important financial consideration and one worthy of serious appraisal. This report has been prepared against this background with various aims, as detailed in section 2.

**Footnote*
A figure of 2.7% (ie 664,000 people) was reported in 1978 (HMSO 1980).

2 Aims

There were five main aims in this survey:

1. to establish an estimate of the financial loss, including capital depreciation and replacement and maintenance costs, resulting from corrosion and materials degradation within the agricultural industry;
2. to identify those farming activities, in terms of product and equipment, which are most susceptible to materials degradation;
3. to consider whether geographical location has any significant effect on degradation;
4. to create a state of awareness of corrosion problems and to encourage preventative action;
5. to make proposals which could lead to the development of a code of practice.

3 Approach

The survey was carried out between 1979 and 1981.

Initial discussions with farmers formed the basis of a questionnaire, which was issued nationwide via the National Farmers Union and the Scottish Farmers Union and by other methods. Details are given in table 1.

3.1 Sample characterisation

The farms responding to this survey were characterised according to distribution of activities (table 2) and by land area

Table 1 Survey details

Methods of distribution	*Postal survey forms*		*Returned, %*
	Issued	*Returned*	
NFU	245	132	54
SFU	245	79	32
Other	90	21	23
Totals	580	232	40

Visits were made throughout the survey period in order to validate claims made by farmers in their response to the questionnaire.

(figure 1); appendix I details the geographical density of required questionnaires.

3.1.1 Farm activity distribution

Table 2 contrasts the survey returns against the most recent census data available at the time from England and Wales (HMSO England and Wales 1977, HMSO UK 1978) and from Scotland (HMSO, Scotland 1978).

Table 2 Farm activity distribution

*Activity**	*No of returns*	*% of total returns*	*% of returns in 1975 census*
1 Specialist dairy	19	8	27
2 Mainly dairy	23	10	12
3 Cattle/arable	17	7	8
4 Sheep	9	4	3
5 Cattle/sheep	25	11	13
6 Predominantly poultry	7	3	3
7 Pigs and poultry	29	12	6
8 Cropping — mainly cereals	30	13	8
9 General cropping	25	11	11
10 Mixed farming	44	19	7
11 Horticulture	(not in this survey)		2

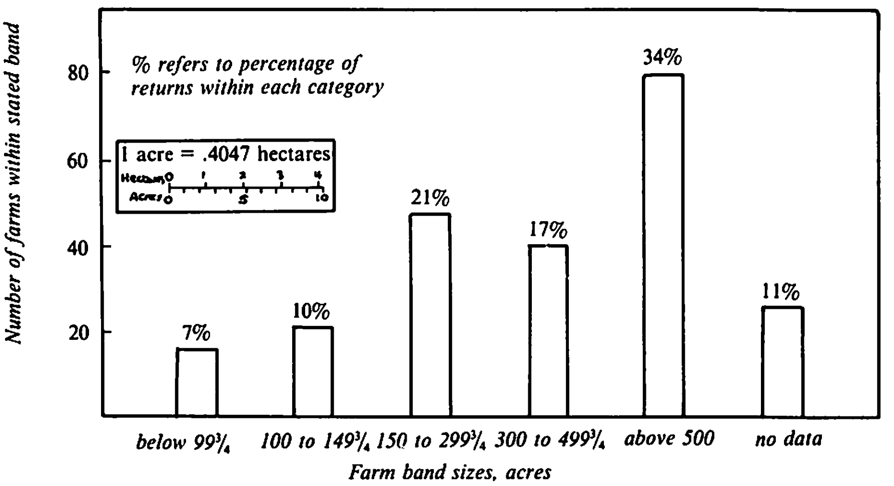
**Activity classes derived from: Farm classification 1975 (HMSO 1977)*

It is notable that the figures for percentage distribution of returns broadly conform to the 1975 census data, which indicates that the sample of farms from which data was received was generally characteristic of the industry as a whole, despite the small sample of farms involved.

3.1.2 Farm size distribution

The distribution of farms according to land area, given in figure 1, shows a higher reply rate from the larger sized farms than would be expected if comparisons were made with the census data of 1975; this may reflect the recent trend towards larger farming units (Manchester Univ 1981), or the input of data from Scotland which will tend to bias the survey towards larger farms. It should be noted that only a relatively small sample of farms could be included in this survey which might, understandably, introduce some difficulty in extrapolating the data to a national level and the report should be read with this reservation in mind. It is possible, of course, that the best organised (and therefore probably least corrosion-prone farms) or the worst organised (and therefore most corrosion-prone farms) responded but there is no way of checking this and probably the sample is reasonable representative. Reports from other countries do not even indicate sample size, etc. This weighting towards larger units probably does not unduly invalidate the generality of the data as there were replies covering the entire spectrum of farm sizes.

Fig 1 Farm classification



4 Financial findings

4.1 Maintenance and repair costs

Individual farms supplied details of capital investment in buildings, fittings and machinery, together with associated maintenance and repair costings. They also provided estimates of corrosion damage, although it was necessary to review this category carefully to allow for non-awareness of the broader aspects of corrosion. Of value in this survey was an estimate of the national repair and maintenance costs which were derived by scaling up individual returns, using the procedure described in appendix 2. The total cost so derived was in excess of £520M (table 3).

Table 3 National estimates of maintenance and repair costs (see appendix 2)

	Costs, £M
Machinery and equipment	334
Buildings and fences	187
Total	521

The last published figure for farm maintenance in 1975 was £175M, but this did not include buildings or fences (HMSO England and Wales 1977, HMSO Scotland 1978).

4.2 Corrosion and material degradation losses

The first order figure for material degradation loss, as derived from data provided by the farmers — see appendix 2 — was £178M, which represents money spent on replacing corroded or degraded parts, including direct labour costs so incurred. The costs of corrosion recorded for each farming activity, are shown in fig 2.

Various features emerge from this information. For example, livestock is common to the three costliest activities, possibly because of damage resulting from the large quantities of animal slurry involved. However, the large area of land associated with livestock is contributory and must not be discounted. Specialist dairy units, which have the highest individual building repair/maintenance problems (appendix 2), rank high in the cost table (fig 2). High costs in other activities (eg cereal and cropping) reflect the incidence of expense weighted more to machinery.

Two additional costs may also be included for a more realistic estimate:
(a) consequential losses and,
(b) capital depreciation.

(a) *Consequential losses* are those that arise indirectly from corrosion. They are not associated with the direct cost of repair or replacement of faulty items. For example, crop losses due to machinery, breakdown, straying of animals through fencing failure, with subsequent overfeeding etc, can be classed as consequential losses. A particular case revealed in the survey is outlined in appendix 3.

The consequential losses were estimated using data reported by the US National Bureau of Standards where second order losses, concerning livestock production, field and orchard cropping,

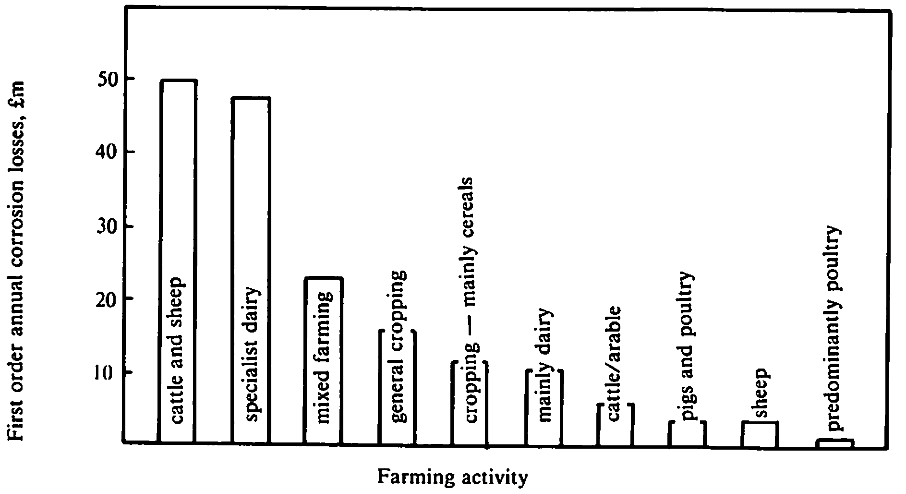


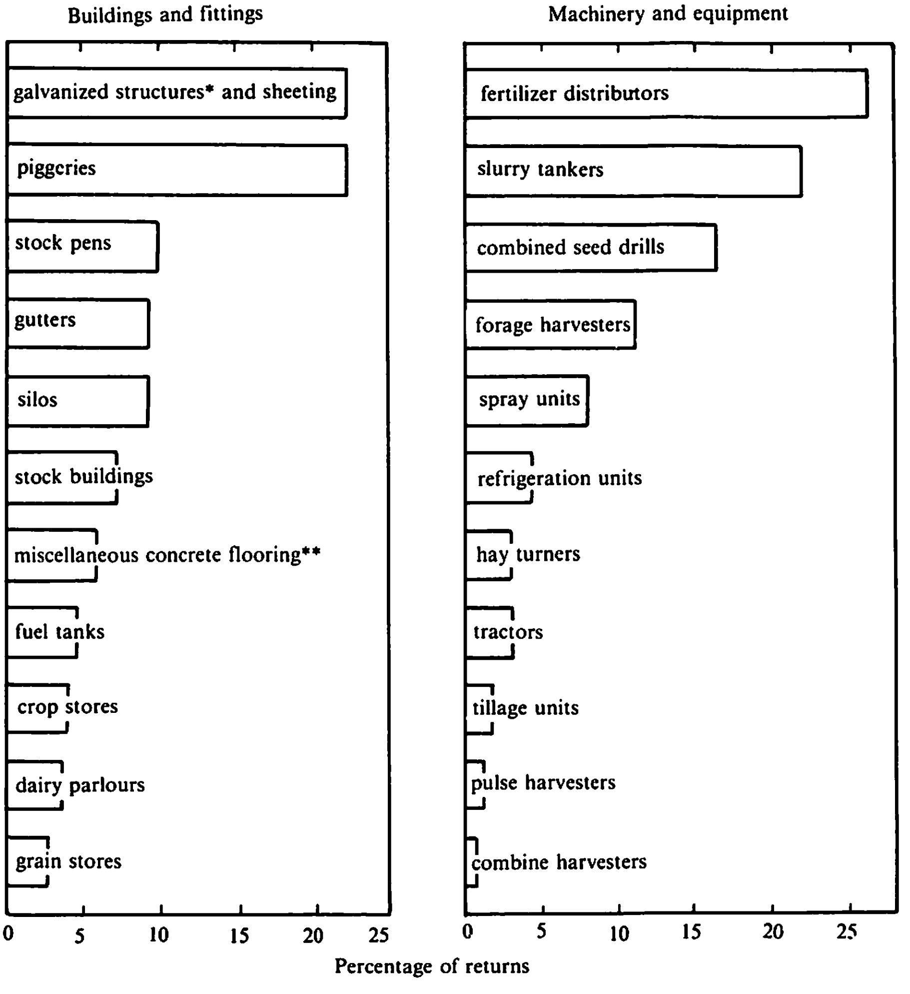
Fig 2 First order corrosion losses

were found to be approximately 1.5 times the first order losses (US National Bureau of Standards 1977). On this basis the UK figure would be approximately £267M. It is appreciated that this is a very approximate approach but it is important that this significant element is not overlooked in any estimate.

Fig 3 Units with severe corrosion damage (response from farmers)

** Structures, comprising frame and cladding are prone to differential lifetimes. The data primarily refers to the "envelope" (ie the cladding of the structure) rather than the frame, although certain problems relate to the soil/ground level of the frame. In most cases maintenance is not carried out, replacement after several years being argued as more cost effective.*

***Floors can be particularly prone to damage unless regularly cleaned of slurry. Some flooring will be included under other categories in the figure (stock pens, buildings, dairy parlours); hard standings are not included.*



(b) *Losses due to capital depreciation* are more difficult to define because some equipment will depreciate more rapidly and have shorter lives than others as a result of corrosion and/or wear. Other equipment is subjected to long idle periods, where poor housekeeping can lead to more rapid depreciation.

Second-hand values of farm equipment are available (BAGMA 1980) and these can be used to provide an estimate of overall depreciation over several years. Assuming a 5 to 7 year replacement programme, the net cost of replacement is found to be approximately 80% of the list prices (see appendix 4). In 1978 the British agricultural industry invested £650M in new plant, machinery and vehicles (HMSO 1980), of which, assuming an 80% depreciation factor, £520M could be attributed to total replacement cost after a 5-year period.

In arriving at the proportion of depreciation due to corrosion, it has been necessary to examine the response from farmers regarding the percentage of equipment suffering from severe corrosion damage to ensure that replacements were actually due to corrosion problems. On this basis it has been possible to estimate that approximately 15-20% of the overall depreciation can be ascribed to corrosion. Hence, on an overall net replacement cost of £520M, the depreciation due to corrosion, at 20%, is approximately £100M. Depreciation of buildings was not considered; any attempt to do so should take into account their design life.

The total losses due to corrosion, as compounded from the three factors discussed above, exceed £500M; table 4 summarises the data.

Table 4 Total costs of corrosion and material degradation

	Cost, £M
Direct losses	178
Consequential losses	267
Depreciation on capital	100
Total cost	545

It will be appreciated that these estimates are subject to varying levels of uncertainty but they represent the first derived figure for such costs in Britain.

In considering the £545M figure, it should be noted that figures for 1978 (HMSO 1980) were assumed still to be realistic. The figure may therefore be a conservative estimate of losses due to corrosion. No attempt to increase the figures for inflation since the survey period has been made because it is recognised that they represent the order of loss, the absolute figures being less significant.

5 Technical findings

5.1 Structures, machinery and fittings

The wide variety of structures, machinery and fittings employed for agricultural purposes creates considerable difficulty in assessing corrosion damage precisely. This is further aggravated by the different types of environment, the seasonal use of certain equipment and machinery, the method of storage, etc. In determining the reasons for damage, emphasis was first given to the types of equipment and structures which were most prone to deterioration as a result of corrosion. Farmers were asked to allocate marks on a points scale from zero (no problem) to 4 (extreme damage), relating to the condition of their installations. Figure 3 shows the overall response from the survey with respect to units suffering from severe corrosion; appendix 5 provides the data reported during the survey. It is to be noted that the age of the various items referred to was not extractable from the survey data. However, whilst other interpretations may thus be admitted, the comments made reflect the opinions of the authors.

As anticipated, there was a wide difference in behaviour. Notable high-risk units are those that handle fertilizers and slurries, where the influence of chemicals, sometimes in association with wear, can be significant. Grass juices themselves are known to be corrosive (Dept of Industry 1977) and machinery involved therewith reflects higher levels of damage, as shown in fig 3. Damage in galvanised structures is perhaps anticipated from an industry which uses such a large quantity of this useful material, usually very satisfactorily. It is important to stress that such deterioration arises when service conditions become more aggressive than perhaps was realised. Galvanised steel does not satisfactorily withstand aggressive soils containing sulphate and chloride, nor acid conditions that prevail at ground level in some buildings, nor severe condensation which is common to many farm buildings. Painting, ie the duplex system of galvanising plus paint (BSI CP231 1966, van Eijnsbergen 1980) may be an economic solution in some cases, although direct replacement could be cost effective. Damage reflected in fig 3 relates primarily to the cladding of buildings.

Piggeries experience very severe corrosion attack, probably as a consequence of intense slurry attack where inside atmospheres may be damp and often contain ammonia in high concentration. Other buildings and fittings show severe corrosion damage under certain conditions (appendix 5), suggesting a need for improvements in protection or control. A separate publication gives more details (Elliott *et al* 1982).

5.2 Fencing and gates

Wire fencing lasts for about 13 to 18 years, but the survey has found that specific environmental circumstances do aggravate corrosion and reduce the overall lifetimes. Those sectors of farming which use active chemicals (eg pig and poultry farms) experience shorter lifetimes, as do farms which are situated in coastal regions as opposed to inland. Appendix 6 gives details of reported fence lifetimes. The effect of chemicals on fencing was further demonstrated in a separate study during the survey period and reports are being prepared.

The major materials employed for gates and posts are steel, wood and galvanised steel and, from the survey, overall average lifetimes were as follows:

galvanised steel	18 years
wood	15 years
mild steel	13 years

The total response, given in appendix 7, showed an exception for cereal farms where galvanised gates required earlier replacement than gates made of wood. This is possibly a reflection of the high use of lime and chemical sprays/mists utilised in this particular type of farming activity. The durability of wooden structures depends greatly upon the type of wood and its treatment. This information was not available for the survey but the effects of corrosion and deterioration due to wood are referred to elsewhere (Elliott *et al* 1982).

5.3 Corrosion hazards with agricultural chemicals

A wide diversity of chemical attack can be anticipated, with problems arising from contact with stored chemicals, farm products or wastes which contain active chemicals, chlorine-containing sterilizing chemicals, and from the effects of internal enclosed spaces of high humidity and the presence of silage and slurry, etc. Therefore, the individual response will vary according to the degree of involvement with the particular metal/chemical combination.

Farmers were asked to list those chemicals which were most damaging to their equipment and their response is plotted in fig 4.

It is evident that most damage has resulted from the use of grain preservatives, notably formic, sulphuric and propionic acids; however, it is also known that fertilizers (especially those containing ammonium nitrate and chloride) and slurries or manures (which may produce organic acids with low pH or ammonia) can be extremely damaging to metals and/or concrete.

Standards and specifications do encourage that reasonable maintenance be given to structures and equipment but the survey has revealed evidence that this advice is not always heeded. Users may be careless and suppliers do not always provide sufficiently clear advice.

5.4 Use of corrosion control measures

The survey sought information about control measures commonly adopted for minimizing corrosion damage. The response from a list provided to farmers is depicted in table 5.

In broader terms, it should be recognised that many failures occur because of a lack of awareness of those factors that aggravate corrosion. Hence,

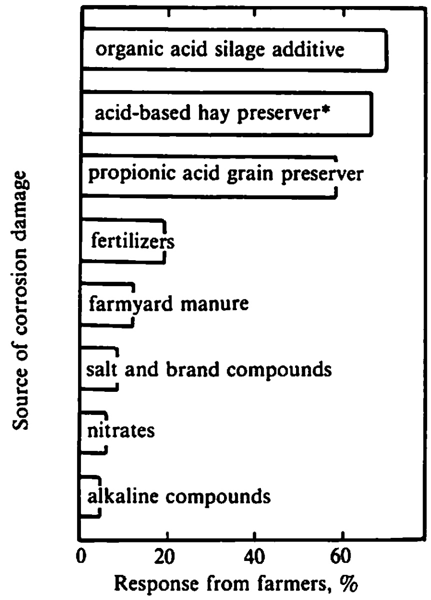


Fig 4 Response for damage associated with given compounds.

* *Sulphuric acid is less attractive nowadays because of the difficulty of ensuring even application; traditional air-drying is often preferred.*

shape, stress, movement, temperature, and compatibility are all of significance in determining whether corrosion can be reduced and avoided, (see also section 6). These aspects and others of a wider nature are the subject of a separate guide. (Elliott *et al* 1982).

6 Conclusions and recommendations

This first pilot survey of corrosion and related problems in agriculture, despite some recognisable dangers in the extensive extrapolation of data from a relatively small sample of farms to a national level, reveals considerable financial losses in excess of £500M. Also apparent is a degree of non-awareness, which is not too surprising if the response and attitudes of other sectors of industry are considered from earlier surveys (Hoar 1971, Elliott 1971). There is obviously a need for a greater level of understanding in most areas or activities of farming, especially if conjoint effects of stress and wear be involved, where corrosion damage can be particularly severe.

Some general observations are developed elsewhere (Elliott *et al* 1982) but specific recommendations can be made as follows, grouped together under several headings.

Table 5 Response to corrosion control measures

Corrosion control measures	*Response, %*
Use of oil and grease on metal parts (including old sump oil)	76
Painting (irregular rather than planned maintenance); cheap and/or unclassified paints	74
Use of rust inhibitors	34
Equipment cleaning by water hosing	58
High pressure hose pipe* used for cleaning equipment and machinery	13

**Note: 66% of farmers have such equipment but many use it only for cleaning stock yards etc.*

Information dissemination
The survey has revealed considerable losses due to materials corrosion and degradation (section 4). It is important that the industry be made aware of these losses and particularly the activities that are most prone to damage (section 4.2). There are many instances where improvements can be made, given the necessary information. Certain features cited in the survey, including any which emerge as controversial need checking in detail, so that more precise action can be taken.

Machinery and equipment
Machinery and equipment manufacturers should provide direct and clearly written recommended maintenance procedures for their products. Cautionary notes about long-term storage should be included along with recommended procedures, especially for those implements that come into contact with more corrosive elements, or those that are subject to long storage in humid stores or barns, etc. These comments do not exclude points made below under 'control measures' with respect to the use of long-term sealants, better designs, etc and the manufacturers and users alike are referred to a freely available publication for more information (Elliott *et al* 1982).

Structures
Due care with regard to location, construction and maintenance is needed with reference to standards where appropriate (BSI, MAFF) and bearing in mind the design life and intended function of the building. Further guides would be beneficial. Problems at ground level need especial care (soils, farm effluent, silage, slurries and chemicals), as do storage conditions (ventilation etc). Fittings and fixtures likewise need attention to specific detail (clean draining surfaces, compatible materials, efficient and effective coatings, sealants etc).

Control measures
Encompassed in these recommendations is a need to create more awareness with respect to temporary protectives for prolonged storage particularly and generally out of season. Long-term sealants and coatings are available but require proper application and repair. Vehicle/equipment advisors could perhaps be established as is the practice in certain East European countries where rules and State standards exist (Vedenkin *et al* 1977).

Farming activity areas with particular problems (eg ammonia in poultry sheds, waste/slurry disposal, silage storage, chemical/fertilizer stores, etc) need to be better acquainted with specific control measures, (more resistant materials, better structural design, better coating technology etc).

Advice
A corrosion and maintenance advisory service (CAMAS) should be established, possibly as an extension to the Agricultural Development and Advisory Service in its architectural and mechanisation divisions. Training courses in colleges should include relevant background information about corrosion and degradation of materials, with emphasis on preventative maintenance, bearing in mind the heavy capital investment in much of the equipment used in this industry. Short refresher courses could be organised, or individual seminars run, at times when the farming community congregate at shows and exhibitions.

Acknowledgements

The authors gratefully acknowledge the financial support of this work by the Agricultural Research Council. Thanks are due to the many farmers, equipment and machinery suppliers, farmers unions, trade show organisers and several sections of the Agricultural Development and Advisory Service who were so helpful. Useful discussions with Dr J K R Gasser of the Agricultural Research Council, Mr D O Jones of the Department of Agricultural Economics in the University of Manchester, Mr M Haywood, Chairman of the Building Working Panel, ADAS, and Mr B Finney, Chief Mechanisation Adviser, ADAS, are also acknowledged.

It should be recognised that the findings reported here came out of the survey and do not necessarily represent the personal views of the individuals concerned.

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Appendix 1 — Survey distribution and returns

Nearly 600 questionnaires were distributed via the National Farmers Union and the Scottish Farmers Union and general details of the returns are given in the report (table 1). The actual returns by county or area (Scotland) are noted below:

The sample of farmers who replied to the survey was smaller than originally had been anticipated but the distribution was felt to cover the country adequately. It was hoped that a geographical appraisal could have been attempted; unfortunately the weighting of replies did not permit this. The large response from the Scottish farmers was mentioned in the main text.

England — *Total Returns: 127*

Avon 1; Bedfordshire 4; Berkshire 3; Buckinghamshire 0; Cambridgeshire 5; Cheshire 3; Cleveland 1; Cornwall 5; Cumbria 4; Derbyshire 3; Devon 3; Dorset 5; Durham 0; Essex 7; Gloucestershire 4; Gt Manchester 5; Hampshire 1; Hereford and Worcester 7; Hertfordshire 4; Humberside 1; I.O.W. 4; Kent 6; Lancashire 4; Leicestershire 0; Lincolnshire 5; Norfolk 2; Northumberland 2; Northamptonshire 1; Nottinghamshire 4; Oxfordshire 1; Salop 5; Somerset 2; Staffordshire 0; Suffolk 2; Surrey 1; Sussex 4; Tyne and Wear 0; Warwickshire 1; W Midlands 0; Wiltshire 2; North Yorkshire 8; S W Yorkshire 2.

Wales — *Total Returns: 26*

Clwyd 2; Dyfed 2; Glamorgan 3; Gwent 4; Gwynedd 9; Powys 6.

Scotland — *Total Returns: 79*

Aberdeen 14; Angus 5; Argyll 3; Arran 2; Ayr 8; Banff 0; Borders 2; Bute 0; Caithness 3; Dumfries 8; Fife 2; Forth Valley 2; Inverclyde 2; Islay 1; Kintyre 1; Lanark 1; Lothians 4; Moray 1; Orkney 12; Perth 2; Ross/Black Isle 2; Shetland 0; Wigtown 4.

Appendix 2 — Analysis of survey returns

The table in this appendix provides a breakdown analysis of costs relating to the period 1979-80. The authors have some reservations about the method of estimation but it represents the best approach available to them. The total direct corrosion and materials degradation costs are discussed in the main text (section 4).

The data presented in the table have been produced from information supplied directly by farmers, who provided estimates of the value of their machinery, buildings and equipment, the amount expended on maintenance and repair, including labour costs, and the proportion ascribed to corrosion. Random follow-up visits were made in order to assess the accuracy of the replies which enabled the authors to make adjustments to allow for such effects as accidental damage. Nationwide estimates were derived using available census data (HMSO 1978). Thus, average values of capital assets suggested by farmers (column I) were multiplied by the total land area for each farming activity (column II) to provide estimates of the nationwide total capital assets (column III).

Farmers' estimates for the amount of "expenditure" required to maintain machinery and structures/fencing, expressed as a percentage of the capital involved, are given in columns IV and VI, respectively. Nationwide costs for maintenance were derived by multiplying these values by the total assets data (column III). The respective costs for machinery and structures/fencing are given in columns V and VII; total maintenance costs are given in column VIII.

The direct cost due to corrosion and materials degradation per farming activity (column X) was obtained as the multiple of the averaged values of the estimates provided by farmers (column IX) and the total assets (column III); the estimates by farmers (column IX) were given in terms of the percentage of their capital assets.

	I	II	III	IV	V	VI	VII	VIII	IX	X
Farming Activities *(-) refers to number of replies for basing estimates*	*Average of estimates of capital assets per acre, £*	*Total area of land for eaching farming activity from census, acres × 10⁶*	*Total assets for Britain, £M*	*Average of capital assets needed to maintain machinery on individual farms, %*	*Total costs for machine maintenance in Britain, £M*	*Average of capital assets needed to maintain structures and fences on individual farms, %*	*Total cost to maintain structures and fences in Britain, £M*	*Nationwide cost of maintenance, £M*	*Total assets attributed to corrosion and materials degradation, %*	*Nationwide cost of corrosion and materials degradation, £M*
	see note (a)		see note (b)	see note (c)	see note (d)	see note (e)	see note (f)	see note (g)	see note (h)	see note (i)
1. Specialist dairy(12)	500	4.61	2300	3.27	75	2.41	55	130	2.07(14)	48
2. Mainly dairy(18)	300	2.95	885	3.26	29	1.14	10	39	1.28(19)	11
3. Cattle/Arable(16)	305	1.96	598	3.93	24	1.44	9	33	1.09(15)	7
4. Sheep(9)	65	5.96	387	2.79	11	2.38	9	20	1.00(9)	4
5. Cattle/Sheep(18)	390	7.61	2968	1.92	57	1.68	50	107	1.71(22)	51
6. Predominantly poultry(5)*	1470	0.09	132	1.71	2	1.02	1	3	0.70(5)	1
7. Pigs/poultry(22)	665	0.612	407	2.61	11	0.92	4	15	1.09(26)	4
8. Cropping — mostly cereals (25)	290	4.19	1215	3.48	42	0.89	11	53	1.04(21)	13
9. General cropping(18)	370	4.07	1506	3.41	51	1.27	19	70	1.04(18)	16
10. Mixed farming (30)	335	3.45	1156	2.77	32	1.67	19	51	1.96(33)	23
				Totals:	334		187	521		178

**Sample size small; figures may not be a true representation of category.*

Notes for table

(a) Average figures based upon replies received from farmers.

(b) These totals are derived by multiplying columns I and II.

(c) These figures represent the averages of estimates to maintain machinery provided by farmers in each activity.

(d) These Nationwide costs for machine maintenance obtained by multiplying columns III and IV.

(e) These figures represent the averages of estimates to maintain structures/fences provided by farmers in each activity.

(f) These Nationwide costs for maintenance of structures/fences obtained by multiplying columns III and VI.

(g) Nationwide costs derived from adding columns V and VII.

(h) Average estimates based on replies received from farmers; index numbers refer to number of replies.

(i) Overall costs for each farming activity obtained by multiplying columns III and IX.

The farming activities numbered in the table are based on activities defined within recent census reports (HMSO UK 1978, HMSO Scotland 1978). These can be summarised as follows:

(1) 75% or more in dairying;

(2) >50% and<75% in dairying;

(3) (4) (5) — more than 50% in livestock rearing and fattening of which 75% or more are cattle (3), 75% or more are sheep (4), and, other holdings with 50% in livestock rearing (5);

(6) 75% or more in pigs and poultry of which 75% or more are poultry;

(7) >50% and <75% in pigs and poultry;

(8) >50% in cropping of which 50% or more are cereals;

(9) >50% in cropping of which <50% are cereals;

(10) ≯50% in any main category. Note also for this survey "cereals" refers to wheat, barley and oats.

Appendix 3 — Consequential (indirect) losses
Consequential losses are those that arise as an indirect result of corrosion and do not include the direct cost of repair or replacement. The findings of the U.S. National Bureau of Standards (1978), which suggest that the indirect losses are about 1.5 times the direct losses, were adopted in the present survey (section 4.1). It is obvious that such values are conservative estimates in some cases, as can be noted from a case study examined during the survey:

> A high horsepower tractor unit had repeated bolt failures when a particular heavy duty rotovator was fitted. The bolts fractured frequently, which necessitated safety inspections every two days. The inspection programme (to ensure safe operation) required two men working for two hours every two days over a six week working period, resulting in a manpower requirement of approximately 60 man hours.

The first direct loss, (ie the cost of the new bolts plus the cost of labour for 60 man hours) is approximately £150. However, particularly significant to the farmer was the resultant crop loss because 25 acres of cereal were sown late because the ground could not be prepared in time. This resulted in a 20 ton short-fall in crop production. With 1979 prices of £100 per ton this represents a consequential loss of £2000.

Appendix 4 — Estimate of depreciation
It is possible to estimate the loss in value of farm equipment with condition and age, using available price guides (BAGMA 1980). Table 4.1 displays data for a representative selection of farm equipment of different size and type, which is assumed to have survived a seven-year period of use. The items selected are those that might be expected to have long lifetimes. The general trends obtained therefore tend to be optimistic because other equipment will not be in a saleable condition after 5-7 years.

Table 4.1 Relative costs and re-sale values after 7 years

Item	*Cost when new in 1973**	*Cost new in 1980***	*Trade-in value (1980)*	*2nd-hand re-sale price (1980)*	*Auction price (1980)*
Balers	100 units	320 units	35 units	50 units	20 units
Combine harvesters	100 units	350 units	45 units	65 units	no information
Tractors	100 units	405 units	45 units	70 units	45 units

* *Original costs of equipment equated to an arbitrary value of "100" units.*
** *Cost in 1980 scaled from the 100 units base.*

Depreciation values have been derived by comparing the difference in price of the new item against the trade-in value. Hence the net % outlay can be obtained (table 4.2).

Table 4.2 Depreciation of equipment over 7 year period

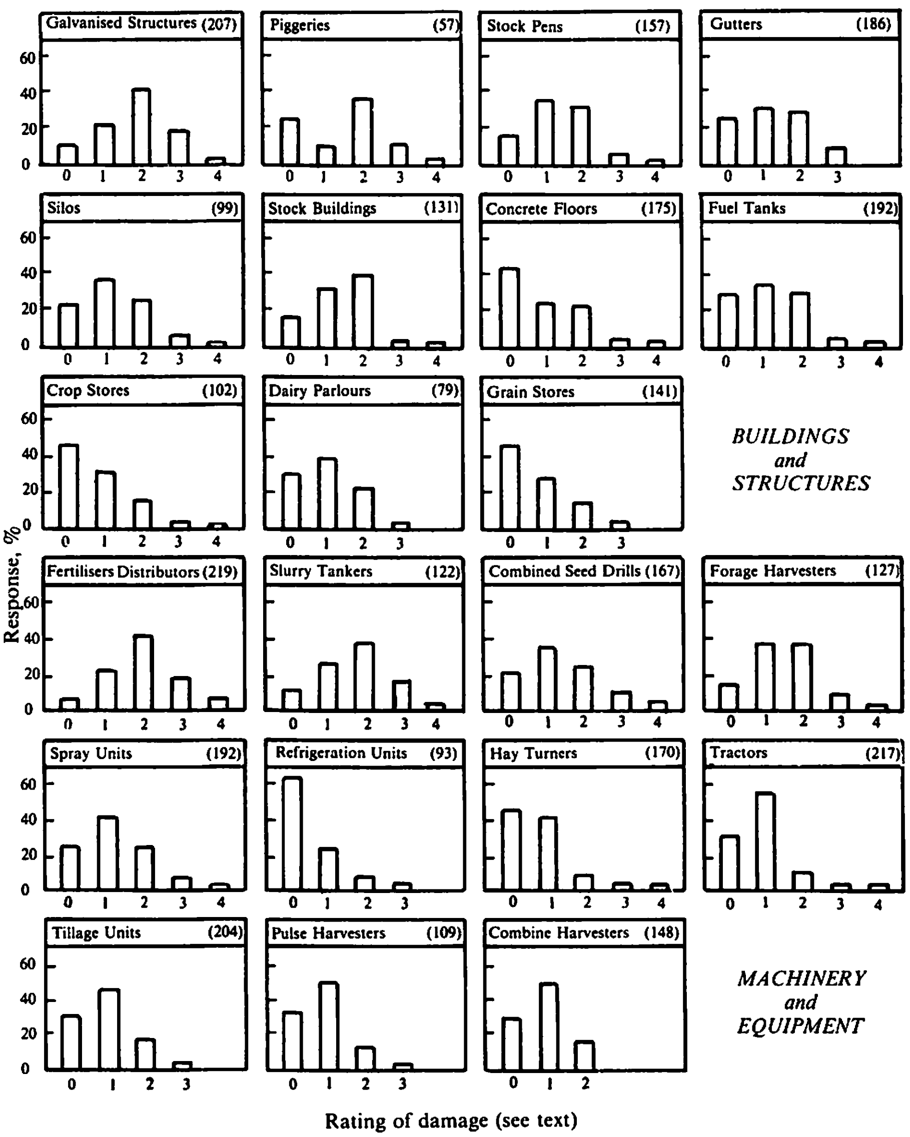
Item	*Cost of new item (a)*	*Trade-in value (b)*	*Net outlay* $\frac{a-b}{a} \times 100$
Balers	320 units	35 units	89%
Combine harvesters	350 units	45 units	87%
Tractors	405 units	45 units	89%

Hence, the net outlay in terms of the current book price list over seven years is close to 90%. A similar analysis (not shown) for a 5 year period reveals a net outlay due to depreciation of about 76%.

According to available statistics (HMSO 1980) approximately £650M was the book purchase value of all equipment sold in 1978. With the current recession, a similar figure has been assumed for 1980, so, with a net outlay value of 80% for depreciation it is possible to derive a total figure of £520M (ie 80% of £650M).

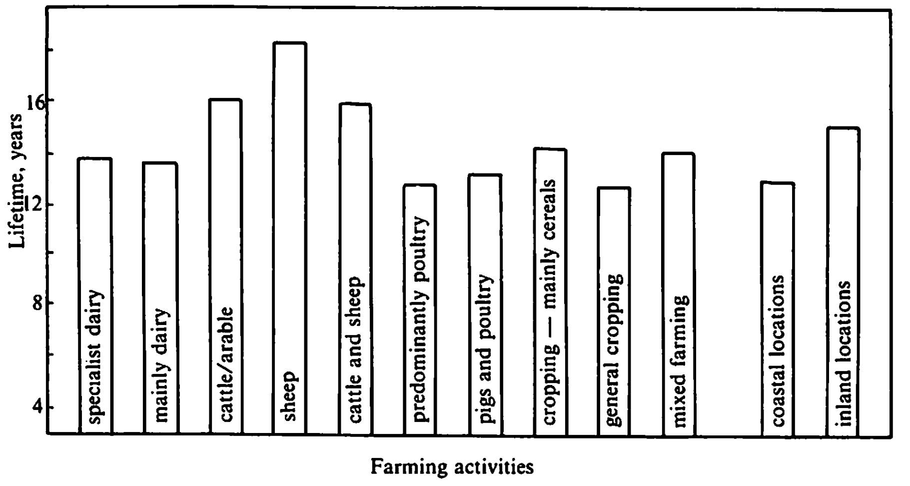
Appendix 5 — Damage to agricultural structures, machinery and fittings
The figures below show the extent by which corrosion problems arise as revealed from the survey questionnaires. The following scale has been used throughout:
0 = no problems; 1 = superficial damage (paint loss); 2 = slight damage (rusting, pitting etc); 3 = severe problems (thinning or perforated sections; 4 = extreme problems (risk of collapse, fractured/ cracked, requires replacement).

Appendix 5



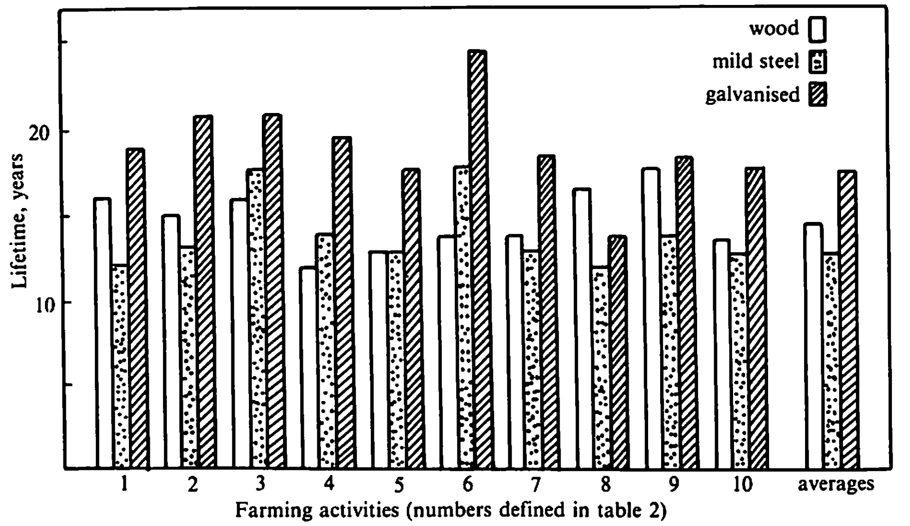
Appendix 6 — Fence lifetimes
The average lifetimes for wire fencing for the various farming activities are plotted in the figure, which also includes estimates for coastal and inland locations. These estimated lifetimes were produced from information solicited by questionnaires and from follow-up meetings with a 10% random sample of farmers involved with the survey.

As anticipated, lifetimes in coastal areas are some 1-2 years shorter because of the effect of chloride-laden mists. Fence life is longest on sheep farms, which would be expected because relatively small quantities of aggressive chemicals are associated with such activities. The effect of non-corrosion factors, such as erosion and impact damage by livestock and farming equipment will also be contributory to the overall lifetimes reflected in the table.



Appendix 6 Average lifetimes of fences over all farming activities

Appendix 7 Average lifetimes of wooden, mild steel and galvanised gates over all farming activities.



Appendix 7 — Gate lifetimes
The collected survey response over all categories is summarised in the figure, which shows the overal benefits from using coated steel. The information was collected in the same manner as outlined in appendix 6/

Particularly of interest is the apparent benefit of wood over steel in several of the activity classes. In one case wood outlasted galvanised steel (cereal and cropping activities), which is possibly a reflection of the high use of lime, and other chemicals which can be particularly damaging to zinc. There is also less associated impact damage because of the absence of livestock.

INSTITUTION OF AGRICULTURAL ENGINEERS ANNUAL CONFERENCE

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10 May 1983

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Further details from: Conference Section, The Institution of Agricultural Engineers, West End Road, Silsoe, Bedford MK45 4DU.

Agricultural odours: some control procedures

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Odour nuisance

THE most obvious form of pollution caused by agriculture is the unpleasant odour associated with livestock farming. There is no doubt that livestock farms of *all* types do sometimes create unpleasant smells; as intensification of the livestock industry has increased, the problem of smells has become more acute.

A recent survey on the incidence of agricultural odour nuisance (IEHO 1981) has indicated that land spreading operations are the most frequent source of complaint, followed by animal housing and slurry/manure storage facilities. Odour nuisance is sometimes also related to silage handling and storage and to processing and handling of other animal feedstuffs, eg swill boiling.

Smells may be produced almost continuously, eg livestock housing, but (reflecting the survey findings) the most objectionable odours are usually intermittent and arise when manures, which have been stored under anaerobic (septic) conditions, are agitated, transported or spread on land.

Whether or not a smell causes a nuisance depends upon its offensiveness, its strength and duration and how many people it affects. Atmospheric conditions, particularly wind direction and strength, may have an overriding effect.

Legislation

Relevant legislation in England and Wales is contained in only two Acts. The Public Health Act (1936) (Section 91) implies that any premises or animal kept in such a state or manner as to be prejudicial to health or a nuisance, or any accumulation, deposit, dust or effluvia (exhaust air or gas) which is prejudicial to health or a nuisance, may be regarded as a 'statutory nuisance'. Under the Act, it is the duty of the local authority to undertake periodic inspection of their districts for the detection of statutory nuisances and to serve an abatement notice on any person who is responsible for a nuisance (Section 93 of the 1936 Act). If the requirements of an abatement notice are not complied with, expensive legal proceedings may be taken, which could result in a further abatement order or a fine. In extreme cases, the restrictions may be so severe that offending premises may have to cease keeping livestock.

The Public Health (Recurring Nuisances) Act (1969) strengthens the powers of the 1936 Act with respect to recurring nuisances. It provides for a prohibition notice to be served where the local authority are satisfied that a statutory nuisance has occurred and is likely to recur on the same premises. Such a notice may be served whether or not the nuisance exists at the time of service and whether or not an abatement notice has been served under Section 93 of the Public Health Act (1936). If the notice is not complied with, or if the nuisance recurs, the magistrates may on application by the authority make a nuisance order in the same way as if the authority had acted under Section 93 of the 1936 Act.

Although there is no comprehensive law relating to odour control that applies to the whole of the United Kingdom, the general intent and style of legislation is similar throughout.

Odour control

Due to the intermittent and variable nature of odour problems, their control tends to be difficult and expensive. Odours may be tackled in various ways, ranging from simple adjustment of management routine, to the use of highly specialised treatment systems. It is clearly important to isolate the prime source(s) of a nuisance, in order that appropriate measures may be applied and stand some chance of success.

Management

Siting of new buildings and manure stores

Under conditions of neutral stability (eg overcast, light winds), the influence of large buildings or a large lagoon may extend outwards to a distance of several hundred metres before significant dispersion of odours by atmospheric diffusion is likely. Detailed meteorological records for cumulative frequency of wind direction and atmospheric stability should be consulted when considering the size and shape of a buffer zone around a new facility.

Building design

Good design is essential for efficient operation. There should be no inaccessible areas in pens or slurry channels that may be difficult to clean and could accumulate decomposing waste. Building design will influence the type of waste to be handled; solid manure systems, when well managed, will encourage composting and can be less odorous than slurry systems; systems which allow the daily removal of wastes from the building, eg flushing or scrapers, will minimise the amount of decomposing material releasing odours into the building atmosphere (Jongebreur *et al* 1980).

In slurry systems, the surface area of stored slurry may be an important factor controlling the total amount of odour released into the atmosphere of the house; thus the area of slatted floor (total/partial slatting) is important. Ventilation systems with air inlets/outlets below the slats will encourage the release of odours from fan exhausts.

In controlled environment pig housing, one of the benefits of a well designed ventilation system has been shown to be cleaner animals (Randall 1982).

Cleanliness and hygiene

If animals are allowed to coat themselves in dung, the rate of release of volatile odorous compounds from the dung will be greatly increased, due to increased surface area and the body heat of the animals. Wastes/effluents should, therefore, not be allowed to accumulate in corners of buildings or on large areas of open yards. Fan exhaust vents and pens should be cleaned thoroughly between batches. Manures and slurries should be removed to properly constructed storage facilities; all effluent run-off from buildings, collecting yards and manure storage compounds should be collected for controlled disposal.

Livestock husbandry

In solids-based systems, provision of adequate bedding/litter will assist in keeping stock clean. Leaking drinkers and water spillage on poultry litter should be controlled in order to prevent areas of anaerobic fermentation and odour release.

In slatted floor accommodation for pigs, pen cleanliness has been shown to be affected by stocking density, being best at about 120 kg/m^2 liveweight and deteriorating at higher and lower rates (Randall 1982).

Overstocking in litter-based poultry will result in an overloaded, offensive litter; for broilers about 0.05m^2/bird is the commonly quoted guideline. Understocking in such poultry units may also be undesirable, since this may result in a dry and excessively dusty litter, increasing the dust burden in exhaust air.

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Livestock diet may have some influence on odour release; dairy by-products are said to increase the offensiveness of excreta, eg from birds fed on a ration that includes milk powders and from whey-fed pigs.

Disturbance of pigs, from their established social group or from an established routine, is liable to cause upset and result in dirty animals; animals should be disturbed as little as possible.

Production and storage of feed

The concept that odours may be absorbed and transmitted in the air on dust particles has been proposed by workers in the USA (Hammond *et al* 1979). Excessively finely ground feeds and long feed drops into bins or onto floors contribute unnecessarily to dust levels. Where milling and mixing is carried out on site, additives such as tallow will help to control dust.

The smell of silage or ensiled food processing wastes, eg vegetable trimmings/peelings, is sometimes offensive to urban dwellers. Well made silage should smell sweet and inoffensive; there is no substitute for good production technique and proper provision for collection and storage of any effluent. Odours arising during the boiling of swill may be reduced by careful control of the cooking process.

Storage design

Storage facilities should be adequately sized, with allowance for polluted run off, wash water and rainfall (MAFF 1982). Capacity should be sufficient to cope with occasional extremes of rainfall, as well as under average conditions.

Solids storage compounds may usefully be divided, keeping fresh and older waste materials apart, thereby allowing some composting and stabilisation to occur, before emptying is required.

The formation of a crust on a lagoon or in a storage tank will help to retain odours and may be preferable to regular agitation (and intense odour release), provided that mixing may still be achieved, prior to emptying. Stores which allow liquid drainage (eg sleeper walls, strainer box) do not require agitation.

Shelter belts/windbreaks

Tree screens around a unit will shield it from public view and improve its appearance. The main effect of a windbreak will be to encourage turbulence and increase the depth of mixing and, therefore, the dilution of an odour, downwind of source. Depth of mixing is increased to roughly twice the height of the windbreak (Gloyne 1954); a belt of trees several metres in height will usefully increase the dispersion of an odour.

Vegetative screens may also provide some marginal effect due to physical trapping of dust particles and vapour exchange through leaf stomata.

Land application of wastes

ADAS Meteorologists are able to predict when weather conditions will be most favourabe for rapid dispersion of odours and, therefore, when annoyance caused by manure spreading operations will be minimised.

Odours disperse most slowly on clear nights with light winds, when the atmosphere is in a "stable" condition; slow moving air will be mixed with only a shallow depth of air above. Unstable conditions, in which odours are diluted rapidly occur on bright days, especially if associated with strong winds; air mixing will be much greater and may be over a depth of about a mile. Useful indicators of atmosphere stability are wind and sun during the day and wind and cloud cover at night; conditions affecting the likely nuisance created by manure spreading have been summarised in two tables (Bird 1978).

Table 1 Conditions favourable for dispersion of odour during the night

Wind speed	*Cloud cover* Clear	Broken	Overcast
Light	1	1	2
Moderate	2	2	3
Strong	3	3	4

Table 2 Conditions favourable for dispersion of odour during the day

Wind speed	*Sun* No sun	Weak sun	Bright sun
Light	2	3	4
Moderate	3	4	5
Strong	4	5	5

In the tables, a rating of 1 is given to conditions in which most annoyance is likely and a rating of 5 for those conditions in which the weather will give most help in dispersing and diluting odours.

Carcase disposal

Carcases are occasionally left for days prior to disposal by burial or incineration and putrefaction may result in extremely obnoxious odours. Simple pits have been used successfully to deal with carcases from small units (MAFF 1980); a manhole cover prevents escape of odours. On large units, an efficient incinerator should be sited well away from any neighbour or may be fitted with odour contol equipment eg an after burner or an electrostatic precipitator.

Public relations

This is often the most lacking aspect of the farmers' approach to odour nuisance. Neighbours are less likely to complain about odours once the problems of control are more fully understood. The farmer's attitude to the complainant may be critical; a willingness to investigate, to ask for suggestions and to co-operate will, at worst, give some time to study the problem and initiate control measures before legal action imposes difficult restraints on the unit. If possible, near neighbours should be informed of activities (eg spreading) which may affect them.

Farmers should avoid spreading slurries at weekends or in the evening when neighbours are more likely to be about their homes.

The frequency of spreading operations is also important. Most people would accept a period of strong smells for a few days every year, due to intense slurry spreading activity, in preference to continuous/intermittent odours which may be associated with daily handling and spreading.

Odours from land spread manures may persist for several days (Ould and Smith 1981). Application rates should be controlled so that ponding and surface sealing of the soil does not occur. In particularly sensitive areas, manures should be ploughed in as soon as possible following spreading.

Machinery

Solids liquids separation

Separation of the solid and liquid fractions of slurry may be achieved by utilising particle density (settlement or centrifuging) or particle size and shape (screening or filtration).

The solids can be stacked and will compost, producing a stable, odour free, fibrous material. With the liquid fraction, handling problems are reduced, energy requirements of further treatment (eg aeration) are reduced and the lower solids content results in less risk of surface sealing of the soil; the liquid may be absorbed more rapidly by the soil, thereby reducing odour persistence following spreading.

Spreading equipment

Machinery used for slurry application has often been designed for optimum ground cover and speed of application. To minimise odour emission, slurries should be directed downwards in large droplets; low level splash plates are preferable to high trajectory sprays. Slurry curtains and dribble bars are effective, but little used, methods of reducing odour emission during spreading. Simple gate-valve tankers will tend to generate less aerosol particles during emptying than vacuum tankers and vacuum filling tends to encourage de-gassing of wastes and odour release.

Organic irrigation equipment, designed for low level, low volume application of separated slurries and dilute effluents, is now available and has been used with some success in odour-sensitive situations.

Soil injection, a very effective method of spreading slurries without odour, has been used to a limited extent, most notably through contractor services. The method is relatively slow and there are problems in dry, frozen or very stony soils and on uneven terrain. Conservation of slurry nitrogen may, in some cases, partially offset the increased costs involved (Scarborough *et al* 1978).

Treatment systems

Aerobic treatment

Aerobic treatment reduces both the smell and the water polluting potential of slurries.

In order that the aerobic bacteria are adequately supplied with oxygen, intimate mixing of air with the slurry is required and may be achieved by a number of different methods. Commercial aerators vary in their efficiency; most good systems are capable of supplying 1-2 kg oxygen/kWh. Effective treatment also requires efficient mixing of the tank in which the aerator is operating.

The oxygen requirement (and hence, energy consumption and running costs) for effective odour control, will depend upon slurry residence time (Evans *et al* 1979) as well as the volume to be treated. Offensive odour is removed from slurry after as little as 1 day of efficient treatment. Odour, however, is regenerated if the treated slurry is stored following aeration; time for odour regeneration varies from a few hours after treatment at short residence times to, possibly, several months after treatment at prolonged residence times.

On farms, slurries are often aerated continuously in the storage tank in order to control odour; slurry residence time may vary from a few days up to several months. It is clearly more efficient to aerate slurries in a much smaller treatment tank, allowing say 2-5 days retention of slurry, provided that land application is possible soon after treatment.

Advice on the design requirements for aerobic treatment systems is available.

Anaerobic treatment

The process of anaerobic digestion involves the controlled conversion of complex organic molecules (the substrate) into much simpler molecules by bacteria, in the absence of oxygen. Animal wastes contain a large number of highly odorous compounds and digestion of these, usually at elevated temperature, proceeds via a number of intermediates, eg volatile fatty acids. Ultimate products of digestion include: biogas, a mixture of methane (60-70%), carbon dioxide (aprox. 30%), and some hydrogen sulphide; other products include water, ammonium-nitrogen and bacterial protein.

The effect of anaerobic digestion on the smell of animal wastes is not well documented. In recent years, however, reduction in odour offensiveness has been demonstrated on laboratory and pilot scale (van Velsen *et al* 1981, Welsh *et al* 1977), and, more recently, on farm scale digestion (Friman *et al* 1982).

Odour reduction is greater at 35°C than at 25°C and increases with increasing retention time; with pig slurry at 35°C, a minimum of 10 days retention time is required. Other work has shown that, if the solids content of the slurry input exceeds 6%, slurry retention time must be considerably increased, for effective odour control.

Unlike partially aerobically treated wastes, it appears that digested slurries can be stored following treatment, without regeneration of offensive odours.

Chemical additives

The concept of applying a chemical to alleviate odour problems is attractive in terms of convenience. A large number of commercial products are available and may be grouped into five main categories.

Oxidising agents	—	oxidise odorous compounds in anaerobic waste, eg permanganate, hypochlorite.
Deodorants	—	react with odorants, inhibiting their release or neutralising unpleasant odour.
Masking agents	—	compounds with strong but pleasant odours which camouflage malodours.
Digestive products	—	contain bacterial cultures or enzymes aimed at biological control of production and release of malodours. Such products are often claimed to improve solids breakdown in wastes.
Miscellaneous	—	other materials, eg bactericides, disinfectants.

The use of a large number of chemicals, proprietary compounds and feed additives has been reviewed and studied by Warburton *et al* 1979). Based on their investigations, they suggest that, for short-term odour control, such as treatment prior to land spreading, chemical application (eg oxidising agents, masking agents) may have some value (Smith *et al* 1981). Bactericidal compounds appear to give the best long-term odour control from anaerobic decomposition.

It appears that the cost of chemical treatment for effective odour control may be equivalent to aeration and control may not be as reliable. The mechanism by which some of these products function has yet to be confirmed — until some of these processes are more clearly demonstrated, such materials should be treated with caution. It is recommended that more conventional odour control techniques are used.

Air scrubbers/filters

Whilst simple dust filters have been shown to be effective in removing odour carrying dusts from exhaust air, high costs and problems in cleaning suggest that this method is impractical (Eby and Willson 1969). More recently, dust filters have been developed which appear to be relatively easy to clean and for which 60% odour removal is claimed (van Geelan 1982).

Biological air scrubbers, consisting of a supporting medium on which a bacterial floc is established, have also been developed in the Netherlands. Up to 90% reduction in odours units has been measured by van Geelan *et al* (1977). The costs of such units are high, however, and the installation of scrubbers on each fan outlet in a large building would not be feasible, at present.

Compost/soil filters, developed mainly in Germany seem a promising and, possibly, cheaper alternative (Zeisig *et al* 1980). However, the technique is still in the developmental stages and there is insufficient experience of its effectiveness or viability to recommend its adoption on a commercial scale.

Odour measurement

Recently some work has been undertaken by the Agricultural Development and Advisory Service/National Institute of Agricultural Engineering in an attempt to develop a satisfactory means of odour measurement. Extensive work in the Netherlands by Ould *et al* (1981) has shown that sophisticated instrumental analyses of odours are only considered suitable for screening purposes and not as reliable determinants of odour level. Odour level can only be assessed using sensory methods based on the human nose.

The work by the Agricultural Development and Advisory Service/ National Institute of Agricultural Engineering has been directed towards bag sampling methods of collecting odours followed by presentation of the sample to a panel by means of a dilution apparatus. A range of dilutions are offered to the panel. By recording panel response, the odour threshold is determined as the number of dilutions of the sample with clean air, which will result in a 50% level of detection in the odour panel.

The effectiveness of slurry treatment measures has also been assessed by odour panel using the technique devised by Williams (1981).

Such methods of odour measurement are still in the development stages and many problems remain; it is too early yet to interpret or use the results obtained with confidence.

Conclusions

Some of the difficulties of achieving odour control have been discussed. Perhaps the greatest problem at present, is the lack of a recognised method for reliable odour measurement and, thereby, the means of assessing the success of any particular odour abatement measure.

In considering possible control measures, the costs must be taken into account and written against the profitability of the enterprise. Very often tight profit margins justify only the most modest outlay on a particular modification or technique, which will offer no financial return in itself.

It is sometimes possible to effect some reduction in odour nuisance by simple changes in management. Expensive treatment systems should be regarded as a last resort; prevention is better than cure.

Before embarking on a treatment system, it should be remembered that no system can guarantee complete success. It will therefore be worthwhile consulting the local authority for an opinion on whether the estimated results will be acceptable — 90% reduction of a very intense odour may not be good enough.

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Book

Modern Irrigated Soils

MODERN Irrigated Soils' is a strange title. *Managing Irrigated Soils* would have been more apt. The authors outline the particular considerations necessary to gain most benefits from soils which are used for irrigated crop production. The implications for management are drawn from discussions of soil water relationships and the chemistry of soil salinity and sodicity. The subject matter does not include evaluation of land for use under irrigation.

The first half of the book is concerned with developing an understanding of irrigation scheduling. The chapter headings include 'Crop, soil and irrigation relations', 'Soil water', 'Measuring soil water', 'Irrigation methods' and 'Scheduling irrigation'. Important elements of scheduling procedures are outlined, particularly those used by the Irrigation Management Services provided in the USA. Sadly, as yet, news of UK-based services appears not to have crossed the Atlantic divide. Rather more important, a single symbol is used to represent both potential evapotranspiration from a reference crop and evaporation from a free water surface. This can only lead to confusion. I am also unhappy that the authors side-step any justification of one model rather than another to represent changes in the soil water budget. My own opinion is that solutions of the Richards' equation do not offer a practical means of providing realistic representations of soil water movement and root water uptake. Dr Hanks reviews his own work in this area but omits discussion of root water uptake in the available-water-capacity models. The latter are used for irrigation scheduling.

The second half of the book deals with soil chemistry, specifically fertilisers and problems of salinity and sodicity. Three chapters cover fertilisers and the inter-relationship between crop yield, water use and fertiliser application rates. Titles of the remaining chapters are 'Salt-affected soils', 'Irrigation water quality', 'Leaching requirements' and 'Reclamation of poorly-drained and salt-affected soils'. In general, the important work of the US Salinity Laboratory is well summarised. An explanation is given of why salts are leached more effectively through intermittent rather than continuous ponding. This alludes to a truer picture of water movement in field soils than that outlined in the earlier chapter on soil water. The authors chose not to discuss the concept of "critical water table depth" and its practical importance.

When I was first invited to review *Modern Irrigated Soils,* I wondered how it would compare with the FAO/UNESCO and American Society of Agronomy source-books. Despite the assertions on the jacket-cover I would not call this a "comprehensive reference/text". The bibliographies given with the earlier chapters are rather brief. There is a notable absence of full references to material in the FAO Soils Bulletins and Irrigation and Drainage Papers. Descriptions of soil water measurement and irrigation practice are not exhaustive. My reference text would need to include hysteresis in soil water characteristics, calibration of neutron probe and some discussion of border-strip irrigation.

I believe that the authors intended to provide an accompaniment to an undergraduate course in agriculture or in irrigation engineering. In this respect the book has several strengths. The material is well-presented and SI units are used throughout. There are a number of questions included within a study guide for each chapter. These provide a useful check on whether or not the reader has gained a full understanding of the material within each chapter.

Modern Irrigated Soils by D W James, R J Hanks and J J Jurinak. Wiley-Interscience, New York. £23.25

MEP

NIAE 1924 — 1984

The National Insurance of Agricultural Engineering, Silsoe, UK, will celebrate its Diamong Jubilee with an International Conference — AG ENG 84 — at which important topics in agricultural engineering research will be reviewed and specialist agricultural engineers will present their latest research and development via lectures and poster sessions.

The conference will be held in Churchill College, Cambridge University, over the period 1 — 5 April 1984.

The effect of the potato haulm on the haulm pulling efficiency

A Bouman and J Bouma

Abstract

POTATO tubers can be protected from virus infection, introduced into the sap flow of the plant by aphids, by stopping this sap flow through killing or removing the haulm. The haulm may be killed by chemical or heat treatment or removed by pulling. The present study investigates the factors affecting the efficiency of mechanical haulm pulling. If the haulm is to be pulled without breaking the stems, the tensile strength of the stems has to be greater than the force needed to pull out the haulms.

The breaking strength of the stems at a height of 0 cm above ground is such, with respect to the pulling forces, that there is little chance of breakage at most of the varieties, whereas at a height of 10 cm there is a great risk of stem breakage. The length over which the stems have to be displaced in order to achieve a complete separation of the haulm from the tubers in the soil differs between varieties. When the gripping length of three pulling systems, as well as the pulling length are being compared, it appears the gripping length is adequate in the case of the pulling rollers and pulling belts, but inadequate with the pulling wheels.

Aries Bouman

Jakob Bouma

1 Introduction

THE haulm of seed potato plants has to be treated by a certain date fixed by NAK* in such a way that the sap flow to the tubers is discontinued. This sap flow conveys the virus from leaves infected by aphids to the tubers. This date varies from one year to another and depends on the aphid migration, the variety and seed class. Another reason for stopping the growth before the date specified by NAK may be that the desired grade of tubers has been reached.

The sap flow may be stopped by killing the haulm using chemical or thermal means, or by removing it mechanically. In most cases, the chemical method has to be repeated several times in vigorous crops and/or as the result of the weather conditions; it also pollutes the environment. On the other hand such treatment can be carried out with a machine which can be used for other spraying work and which, moreover, leaves few wheel tracks in view of its operating width. Heat treatment has become less attractive because of the high energy costs (Leeuw 1972). Furthermore, the machines used are heavy and have a narrow working width compared with a sprayer (Philipsen *et al* 1974).

Despite the many advantages especially of the chemical method, the practical disadvantages are so great that interest has greatly increased in the mechanical method, ie haulm pulling. This is also promoted by the fact that *Rhizoctonia* infection of the tubers can be considerably inhibited (Bouman 1979). From a multitude of ideas which have been tested over the years, a pulling system using inflated rubber rollers has been developed into a system used on farms. Subsequently, a machine was constructed at IMAG† and incorporated the principle of pulling belts which is also being used on farms at present, as is a variant of this system. In the latter, the pulling belts have been replaced by pneumatic tyres.

In practice, mechanical haulm pulling still leaves many questions unanswered. Therefore it is a primary requirement that both the designers and users are fully aware of the factors which affect pulling efficiency. In the present report, attention is devoted to the effect of the plant, the pulling principle and the shape of the potato ridge upon the efficiency of haulm pulling.

2 Mechanical haulm pulling

THE efficiency of mechanical haulm pulling is assessed from the proportion of stems which have not been pulled and the number of exposed and damaged tubers. A stem which has not been pulled remains attached to the tuber through the roots and stolons, and new leaves may be formed. These leaves may be infected by virus-infected aphids. The tubers can then become infected by the still functioning sap flow.

Incomplete pulling of the stems may be caused by stem breakage, which may arise if the force needed to pull out the stem exceeds the breaking strength of the stem. The stem pulling force is the force needed to pull the stem with part of the roots out of the ground, leaving the tubers in the soil. The breaking strength of the stems is the greatest pulling force at which the stems break. The magnitude of the breaking strength also depends on the position on the stem. It diminishes the further this position is from the root end. Improper feeding of the stem into the pulling mechanism may lead to an excessively high gripping point on the stem, causing stem breakage. Improper feeding may be due to the fact that the stems are not at the centre of the ridge or that the haulm is badly laid. The gripping point is the position at which the stem is being seized by the pulling mechanism. In the study, measurements were made to determine the pulling force and breaking strength at two points on the stem.

The breaking strength of a stem is affected not only by the variety and by the position of the gripping point on the stem, but also by the stem thickness. In view of the latter parameter, it is not possible to characterise the breaking strength of a variety by a single value. To enable this to be done, use has to be made of the breaking stress.

The breaking stress is the maximum breaking force divided by the area of cross section of the stem. In calculating the cross-sectional area of the stem, it is assumed that the stem is circular. The stems were not pulled at all or incompletely pulled if they were fed well inside the pulling mechanism, because the pulling out length was inadequate. This length is the distance over which the stems have to be displaced if the stems which have been pulled loose are to be brought above the ground. The pulling out lengths were determined in the study, from which it was evaluated whether the

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† *Instituut voor Mechanisatie, Arbeid en Gebouwen*

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pulling principle applied is displacing the stems sufficiently to pull them out completely. If part of the pulled stems remains in the soil, secondary growth may take place and this may not be regarded as complete pulling by the inspection authority.

3 Effect of the haulm on the pulling efficiency

As has already been mentioned in section 2, not only the breaking strength and pulling force needed for the stems, but also the pulling out length have a great effect on the pulling efficiency. The present paragraph deals, in turn, with the breaking strength, the pulling force, a comparison of these, and the pulling out length.

3.1 Breaking strength of the stem

3.1.1 Experimental procedure

The breaking strength was determined using specially designed measuring equipment, in which the stems are restrained in two clamps (fig 1).

In order to prevent damage to the stems, the clamps are lined on their inner surfaces with soft rubber having a studded profile. One clamp is mounted on a stationary ring dynamometer, which is connected to a recorder for the determination of the breaking strength. The other holder can be moved along a guide track at a uniform speed. This is done using a screw spindle, which is attached to the shaft of an electric motor via a clutch and reduction gearing.

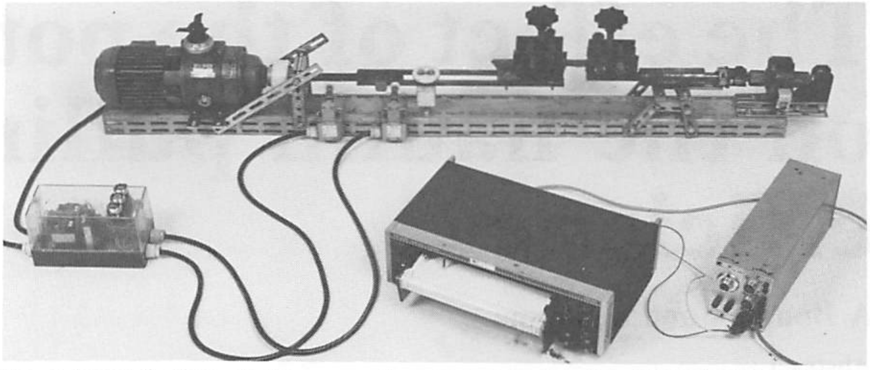


Fig 1 General view of the measuring equipment for the determination of the strength of stems

The breaking strength of the stem is determined by the variety, the position of the gripping point and the thickness. These factors were introduced into the measurements as variables.

In order to determine the effect of variety on the breaking strength, trials with twelve varieties were carried out in three replications. For purposes of these measurements, stems were collected from a number of varieties for each setting.

In the tests, the free piece of stem between the two holders had a length of 0.5 cm. The point at which the stems just reach above the ground and the point 10 cm above the other one, measured along the stem, were adopted as the fixing points for the holders. In practice, the stems are generally seized by the pulling mechanism within this section. The thickness of the stem was also measured at this point. The measurements were carried out at a pulling speed of 0.02 m/s.

3.1.2 Results of measurements of the breaking strength

In the initial stages, problems arose during the measurements with the clamping. As the pulling speed increased, the stems shifted due to the clamp lining. The measurements were, therefore, conducted at a speed of 0.02 m/s only.

Table I gives the results of the breaking strength measurements at a height of 0 and 10 cm above ground for five varieties. The results apply to measurements in which all stems from each plant collected had been used. The average stem thickness is thus representative for the given variety.

The standard deviation (S) evident in

Table 1 Effect of stem thickness (mm) on the breaking strength T_b (N) of the stem, measured at the gripping points 0 and 10 cm above ground with five varieties on sandy clay soil in 1978.

Stem thickness		*Variety*									
		Eersteling		*Prominent*		*Desirée*		*Bintje*		*Irene*	
		T_b	S	T_b	S	T_b	S	T_b	S	T_b	S
mm		*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*
		Gripping point at a height of 0 cm									
5		89	28	158	34			77	24		
6		123	46	229	65			155	31		
7		143	65	255	79	173	30	192	42	217	66
8		168	97	260	121	249	89	274	70	301	140
9		246	66	329	134	265	61	358	118	259	52
10		223	60	339	102	284	50	394	64	423	104
11				363	69	375	60	439	113	428	107
12						374	87	543	127	434	89
13						372	94			491	82
	Mean	165	70	276	105	299	68	306	107	386	102
	Av stem thickness	7.8		8.3		10.0		8.2		10.4	
	S of stem thickness	2.4		2.5		2.8		3.6		1.8	
		Gripping point at a height of 10 cm									
5								126	83	110	49
6								113	40	94	27
7		80	32					—	—	189	45
8		65	26	200	60	137	15	194	87	161	44
9		137	74	223	87	186	64	259	52	198	80
10		166	49	276	117	204	52	294	133	323	81
11		304	139	337	147	220	85	335	55	331	65
12						290	96				
13						315	107				
	Mean	150	74	259	112	225	79	220	87	201	70
	Av stem thickness	9.0		9.4		9.7		8.3		8.5	
	S of stem thickness	2.0		1.8		1.7		3.6		2.0	

Remarks: the number of measurements per variety was 60; S = standard deviation table I shows that the stems differ with respect to their breaking strength even at the same thickness. It will be seen from table I that variety affects the breaking strength when stems of the same thickness are being compared. At a height of 0 cm, the variety Eersteling has a lower mean breaking strength than the other varieties.

No differences were observed between the varieties Prominent, Desirée, Bintje and Irene, despite the greater mean stem thickness of Desirée and Irene. This is partly due to the variation in breaking strength as shown by the standard deviation, S. With the gripping point at a height of 10 cm above ground, no differences were noted between the varieties Prominent, Desirée, Bintje and Irene. The variety Eersteling is less strong. It appears that the thicker the stem, the greater is the breaking strength. This applies both at a height of 0 and 10 cm. With Bintje and Irene the breaking strength is greater at a height of 0 cm than at 10 cm, whereas Desirée shows no tendency towards this. In the case of the varieties Eersteling and Prominent there is no difference.

The breaking strengths of two varieties are compared for two seasons in table 2. The comparison was based on stems of the same thickness. With the variety Bintje the breaking strength for stem thicknesses of 7 and 10 mm was greater in 1978 than in 1979, while for a thickness of 9 mm no difference was noted. In the case of the variety Irene the breaking strength was greater in 1978 for stem thicknesses of 10 and 11 mm, whereas at a thickness of 9 mm there was no difference. A comparison of the breaking strengths in both seasons irrespective of thickness shows that in 1978 both Bintje and Irene had greater breaking strengths than in 1979.

Table 3 indicates the breaking stress of the stems of four varieties and three stem thicknesses in 1977. In this season, not all the stems of a plant were used for the measurements, but a selection was made. The average stem thickness is not representative for the variety. It will be seen from table 3 that at a height of 0 cm the variety Sientje has a lower breaking stress than Bintje, Irene and Alpha.

Table 4 presents the breaking stresses of five varieties in 1979. In that year, all stems of a plant were used for the measurements and the mean stem thickness is representative for the variety. Table 4 shows that the varieties Eersteling and Desirée have both a lower mean breaking stress and lower breaking stress for each group of stem thicknesses than Prominent, Bintje and Irene.

At a height of 0 cm, the stem thickness has no effect on the breaking stress with varieties Eersteling and Bintje, whereas with Desirée, Prominent and Irene it does have an influence. With the latter four varieties, the breaking stress is lower at a greater stem thickness.

At a height of 10 cm, the stem thickness has virtually no effect on the breaking stress with the varieties Eersteling, Prominent and Desirée. In the case of Bintje and Irene, the breaking stress is lower at greater stem thickness. The breaking stress at a height of 0 cm is greater than at 10 cm with the varieties Eersteling, Prominent and Desirée. Bintje and Irene reveal no difference.

Table 2 Effect of the season on the breaking strength T_b, measured with the gripping point at a height of 0 cm, for two varieties, on sandy clay soil in 1978 and 1979

Stem thickness	*Variety*							
	Bintje				*Irene*			
	1978		*1979*		*1978*		*1979*	
	T_b	*S*	*T*	*S*	T_b	*S*	T_b	*S*
mm	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*
7	260	33	192	42				
8					435	86	301	140
9	400	108	358	118				
10	554	76	394	64	602	82	423	104
11					565	126	428	107

Remarks: the number of measurements per variety was 60; S = standard deviation

Table 3. Effect of stem thickness on the breaking stress σ (N/m²) of the stems, measured at the gripping point of 0 cm above ground, for four varieties on sandy clay soil in 1977

Stem thickness	*Variety*							
	Sientje		*Bintje*		*Irene*		*Alpha*	
	σ	*S*	σ	*S*	σ	*S*	σ	*S*
mm	*N/mm²*		*N/mm²*		*N/mm²*		*N/mm²*	
7	4.2	1.2	6.8	0.9				
8	3.7	2.5			8.7	1.7		
9			6.3	1.7				
10	5.6	1.9	7.1	1.0	7.7	1.1		
11					6.0	1.3		
12							4.1	0.7
Mean	4.5	2.2	6.7	1.4	7.5	1.5	6.0	2.0
Av stem thickness	7.7		8.9		8.6		9.2	
S of stem thickness	1.8		1.7		2.3		2.0	

Remarks: the number of measurements per variety and for each stem thickness category was 10; S = standard deviation

It may be concluded from the results that for haulm pulling the stems should be seized as low as possible, since the breaking strength is greater at a height of 0 cm than at 10 cm. There is then less risk of breakage. Whether the breaking strength is adequate to enable the stems to be pulled out without breaking will be discussed in section 3.3.

With four of the varieties, the breaking stress appears to depend on the stem thickness and cannot, therefore, be used as a measure of strength of a given variety. With the variety Bintje, breaking stress was less dependent on stem thickness.

3.2 Force needed to pull out the stems

3.2.1 Experimental procedure

An experimental rig was constructed for the measurement of the pulling force. All stems of a given plant were fixed in a clamp and pulled out of the ground (fig 2). This clamp is attached to a hydraulic cylinder via a ring dynamometer. The ram speed of the cylinder can be infinitely varied by a control valve, so that the measurements can be made at different pulling speeds. The frame with the cylinder can be turned in the vertical plane and adjusted in height. This makes it possible to measure the force needed to pull out the stems at different pulling angles in relation to the ground surface. The ring dynamometer is connected to a recorder for recording the pulling force needed.

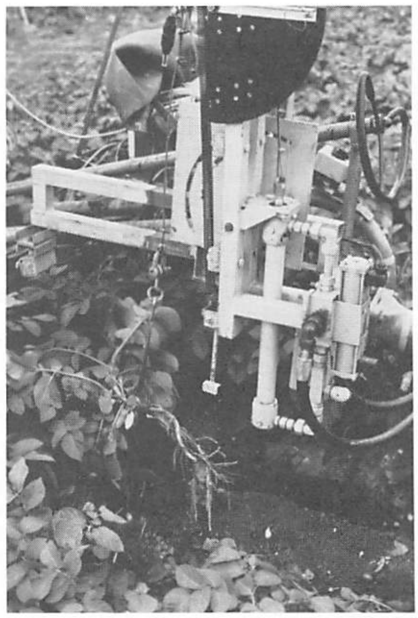


Fig 2 General view of the measuring equipment for the determination of the force needed to pull out the stems

The factors which may affect the force needed to pull out the stems are the number of stems per plant, variety, pulling speed, pulling angle and type of soil.

In the measurements, all stems from a given plant were pulled in one go. If the stems were pulled separately, each succeeding measurement was influenced by the preceeding one. Stem by stem

Table 4 Effect of stem thickness (mm) on the breaking stress σ (N/mm²) of the stem, measured at the gripping points of 0 and 10 cm above ground, for five varieties on sandy clay soil in 1979.

Stem thickness	*Variety*									
	Eersteling		*Prominent*		*Desirée*		*Bintje*		*Irene*	
	σ	*S*	*σ*	*S*	*σ*	*S*	*σ*	*S*	*σ*	*S*
mm	*N/mm²*		*N/mm²*		*N/mm²*		*N/mm²*		*N/mm²*	
	Gripping point at a height of 0 cm									
5	4.5	1.4	8.1	1.7			3.9	1.5		
6	4.3	1.6	8.1	2.3			5.5	1.2		
7	3.7	1.7	6.6	2.1	4.5	0.8	5.0	1.2	5.7	1.7
8	3.4	1.8	6.7	3.1	5.0	1.8	5.5	1.9	6.0	2.8
9	3.9	1.0	5.2	2.1	4.2	1.0	5.6	3.5	4.1	0.8
10	2.9	0.8	4.3	1.3	3.6	0.6	5.0	0.7	5.4	1.3
11			3.8	0.7	3.9	0.6	4.6	1.4	4.4	1.1
12					3.3	0.8	4.8	1.2	3.9	0.8
13					2.8	0.1			3.7	0.6
Mean	3.8	1.6	6.1	2.1	3.9	1.0	5.0	1.4	4.7	1.5
Av stem thickness	7.8		8.3		10.0		8.2		10.4	
S of stem thickness	2.4		2.5		2.8		3.6		1.8	
	Gripping point at a height of 10 cm									
5							6.5	4.2	5.6	2.5
6							2.0	1.4	3.3	0.9
7	2.0	0.9					—	—	4.9	1.2
8	1.3	0.5	4.0	1.3	2.7	0.3	3.0	1.7	3.2	0.9
9	2.1	1.2	3.5	1.4	2.9	1.0	4.1	0.8	3.1	1.3
10	2.1	0.6	3.5	1.5	2.5	0.6	3.7	1.7	4.1	1.0
11	3.4	1.5	3.5	1.6	2.3	0.9	3.5	0.6	3.5	0.7
12					2.6	0.8				
13					2.4	0.8				
Mean	2.2	1.0	3.6	1.5	2.7	0.9	4.3	2.2	4.0	1.3
Av stem thickness	9.0		9.4		9.7		8.3		8.5	
S of stem thickness	2.0		1.8		1.7		3.6		2.0	

Remarks: the number of measurements per variety was 60; S = standard deviation

pulling by the haulm puller may take place, but under the influence of the forward speed it may be assumed that all the stems of a given plant will be pulled practically simultaneously, so that the measuring technique and practice are in agreement. The pulling out force was measured on alternate plants in the row. In this way, successive measurements could not influence one another.

The experiments were carried out on the same trial field on sandy clay soil, from which the stems had been collected for measurements of the breaking strength. As a result, the breaking strengths and forces to pull out the stems could be compared.

The pulling speeds at which the measurements were conducted varied from 0.05 to 0.32 m/s, the pulling angles being 0 and 90°. The pulling out length was measured with three varieties. In these trials, a single stem was pulled by hand, after which the distance between the point at which the stem broke from the rest of the plant and the point of transition from subterranean to supraterranean parts of the stem were determined.

3.2.2 Results of measurements of the force needed to pull out the stems and the pulling length

Table 5 presents the pulling forces, at a pulling speed of 0.2 m/s, needed with four varieties at different numbers of stems per plant. It will be seen from table 5 that with the variety Eersteling, the number of stems has no effect on the pulling force needed. In the case of Bea, Bintje and Irene, there is a tendency towards greater pulling forces with a larger number of stems. However, the standard deviation is so high that no significant effect can be established. The correlation coefficient is small. Variety affects the pulling out force, both when comparing the overall mean and in a comparison of plants with the same number of stems. There is no difference between the varieties Eersteling and Bea, but the pulling forces are smaller with these two varieties than for Bintje. Bintje needs less force to pull the stems than Irene. There is no difference in the average number of stems per plant between these four varieties.

Table 6 shows the required vertical pulling forces for twelve varieties, for two dates in 1977 and one in 1979. A lower pulling speed of 0.03 m/s was used in this case. The results for 1977 show that the pulling forces required for the very early

Table 5 Effect of the number of stems on the pulling force T in a vertical direction, for four varieties on sandy clay soil in 1978 (pulling out speed 0.2 m/s)

No of stems/ plant	*Variety*							
	Eersteling		*Bea*		*Bintje*		*Irene*	
	T_{mean}	*S*	T_{mean}	*S*	T_{mean}	*S*	T_{mean}	*S*
	N	*N*	*N*	*N*	*N*	*N*	*N*	*N*
3	123	34	137	43	197	68	280	33
4	154	35	134	52	290	29	338	54
5	167	34	189	49	299	45	372	43
6	168	61	190	29	311	55	399	66
7			158	15	303	37	377	47
Overall T_{mean}	150		164		293		361	
Oversall S	43		47		51		54	
Av no of stems/plant	4.5		4.9		5.5		5.2	
S of stems/ plant	1.3		1.7		1.6		1.4	
Correlation coeff	0.37		0.37		0.38		0.53	

Remarks: the number of measurements per variety and for each group of stem thickness was 10; S = standard deviation

Table 6 Effect of variety and pulling date on the pulling force T in a vertical direction, for twelve varieties on sandy clay soil (pulling speed 0.03 m/s)

		Date								
		19-7-'77			*5-8-'77*			*24-7-'79*		
Variety	*Maturation category*	*T* *N*	*S* *N*	*No of stems/ plant*	*T* *N*	*S* *N*	*No of stems/ plant*	*T* *N*	*S* *N*	*No of stems/ plant*
Eersteling	Very early	150	43	4.5	—	—	—	186	63	4.5
Bea	Early	164	47	4.9	137	32	5.3	185	55	5.2
Sirtema	Early	186	31	2.9	157	34	3.3	—	—	—
Jaerla	Early	186	59	3.7	177	46	4.6	210	77	3.7
Spunta	Second early	275	50	4.5	235	40	4.5	261	90	3.5
Bintje	Second early	293	51	5.5	284	59	6.4	234	59	4.9
Sientje	Second early	294	51	7.9	275	59	7.0	285	93	5.7
Eigenheimer	Second early	324	51	8.6	314	61	8.5	337	75	10.1
Desirée	Main crop	295	63	4.3	275	57	4.0	268	74	3.4
Irene	Main crop	361	54	5.2	373	62	5.5	387	78	4.3
Alpha	Late	314	69	5.7	314	69	5.5	362	105	4.6
Prominent	Late	324	79	5.7	324	91	5.5	309	84	4.8

Remarks: the number of measurements per variety was 40 on 19-7-'77, 30 on 5-8-'77 and 60 on 24-7-'79; S = standard deviation

and early varieties are lower than those for second early, main crop and late varieties. The 1979 results reveal small, though not significant differences. With respect to the pulling force required, the variety Eigenheimer can be more readily assigned to the main crop group, whereas Desirée is better placed into the second early group.

There were no differences either between the two dates in 1977 or between the seasons. At the second date in 1977, the variety Eersteling had died down to such an extent that it was not included in the measurements.

The required pulling force in a vertical direction is shown for six varieties at two pulling speeds in table 7. Less pulling force is needed by the varieties Eersteling and Jaerla at higher pulling speeds than at lower ones. With the exception of Sirtema, there is a difference also with the other varieties, but not a significant one. At the lower pulling speed, there is a definite difference in the very early and early groups. No difference will be noted in these groups at the higher speed.

Table 8 presents the pulling force in a horizontal direction for five varieties and two pulling speeds. With the variety Prominent, there is a small difference; Sientje, Desirée and Irene did not reveal any differences. The effect of an increase in pulling speed in a horizontal direction is less clearly evident from the results than in a vertical direction.

The pulling force in a vertical and horizontal direction is indicated for five varieties in table 9.

With the varieties Sientje and Irene, the horizontal pulling force is greater than the vertical one in 1979. With the exception of Desirée, the other two varieties show a tendency towards horizontal pulling demanding more pulling force than vertical pulling.

The pulling out lengths are shown in table 10 for three varieties.

The considerations are based on the assumption that the haulm has been pulled if the haulm with the root debris has been completely severed from the tubers and the pulled parts are resting on the ground.

It will be seen from the results that the maximum pulling out length is greater with the variety Bintje than with Prominent and Irene. The maximum value depends on whether all stems have been completely pulled. The general conclusion is that the very early and second early varieties require lower pulling forces than the varieties in the other maturation categories. Moreover, horizontal pulling demands a higher pulling force than vertical pulling. Whether the pulling force will cause the stems to break, in view of a low breaking strength of the stems, will be discussed in section 3.3.

Table 7 Effect of pulling speed on the pulling force in a vertical direction, for six varieties on sandy clay soil

		Pulling speed			
		0.05 m/s		*0.17 m/s*	
Variety	*Maturation category*	*Pulling force, N*	*S* *N*	*Pulling force, N*	*S* *N*
Eersteling	Very early	222	48	166	25
Sirtema	Early	154	51	176	47
Jaerla	Early	237	64	165	53
Bea	Early	187	47	164	43
Spunta	Second early	271	44	265	72
Eigenheimer	Second early	405	90	334	81

Remarks: the number of measurements per variety and for each speed setting was 40; S = standard deviation

Table 8 Effect of pulling speed on the pulling force in a horizontal direction, for five varieties on sandy clay soil

		Pulling speed			
		0.2 m/s		*0.32 m/s*	
Variety	*Maturation category*	*Pulling force, N*	*S* *N*	*Pulling force, N*	*S* *N*
Sientje	Second early	180	73	175	57
Desirée	Main crop	275	56	280	91
Irene	Main crop	182	64	214	31
Alpha	Late	422	107	249	36
Prominent	Late	287	79	227	85

Remarks: the number of measurements per variety and for each speed setting was 40; S = standard deviation

The high value for the variety Alpha at a pulling speed of 0.2 m/s cannot be explained.

Table 9 Effect of the direction of pulling on the pulling force T for five varieties in two seasons on sandy clay soil

		Date							
		9-8-'78				*15-8-'79*			
		Direction of pulling							
		Vertical		*Horizontal*		*Vertical*		*Horizontal*	
Variety	*Maturation category*	*T* *N*	*S* *N*	*T* *N*	*S* *N*	*T* *N*	*S* *N*	*T* *N*	*S* *N*
Sientje	Second early	254	63	373	59	175	50	345	83
Desirée	Main crop	285	57	274	84	—	—	—	—
Irene	Main crop	311	58	385	58	222	64	321	92
Alpha	Late	—	—	—	—	346	90	374	93
Prominent	Late	—	—	—	—	349	93	354	73

Remarks: for both dates 40 measurements were made per variety and for each direction of pulling; S = standard deviation

3.3 Comparison of the breaking strength of the stems with the force needed to pull out the plant stems

Potato haulm can be pulled without breaking the stems if the breaking strength is sufficiently high to be able to sustain the pulling out force. As already mentioned above, it is assumed that all the stems of a given plant are being pulled simultaneously (see section 3.2.1).

The comparison between the breaking strength and pulling force is based on the following points.

The total breaking force of the stems of a given plant was calculated as that value for which the probability of breaking a single stem is 5% or less, multiplied by the average number of stems per plant.

In the calculation of the percentage of plants with which stem breakage may occur, the mean pulling force and the standard deviation have been taken as starting points. The difference between the total breaking strength of the plant and the mean pulling force is then calculated.

The probability that stem breakage will occur, can be calculated using the mean and the standard deviation of the pulling forces if the breaking strength of a plant is taken as being fixed, eg for Eersteling, the breaking strength is taken as 225 N. If the distribution of pulling forces is assumed to be a normal distribution, then the possibility of stem breakage can be calculated using a table of the standard normal distribution. For Eersteling this probablity is calculated as the probability that a normal variate with mean of 186 and a standard deviation 63 exceeds the value 225 N, ie 27.4%.

The table shows that at a height of 0 cm there is little chance of stem breakage with four of the five varieties examined and at a height of 10 cm, there is a risk with only one variety. If the stems are to be pulled properly, they should be seized as low as possible.

Table 10 Percentage of stems with a certain pulling out length for three varieties on sandy clay soil

Pulling length cm	*Percentage of stems at each pulling out length for three varieties, %*		
	Bintje	*Prominent*	*Irene*
<12	5	5	2
12	2	11	2
13	4	10	5
14	5	16	9
15	5	13	16
16	11	14	18
17	13	15	15
18	15	6	8
19	12	5	11
20	5	3	6
21	14	2	6
22	5		1
23	2		1
24	1		
25	1		
Mean pulling length, cm	16.3	17.3	15.2
standard deviation, cm	3.8	2.5	3.2

Remarks: the number of measurements per variety was 100

Table 11 Mean pulling force and breaking strength of each plant, and percentage of plants with which stem breakage may occur, for five varieties and two positions of the gripping points on the stem (sandy clay soil)

Variety	*Pulling force*	*Standard deviation*	*No of stems per plant*	*Height of gripping point*			
				0 cm		*10 cm*	
				Breaking strength per plant	*Percent of plants with a probability of stem breakage*	*Breaking strength per plant*	*Percent of plants with a probability of stem breakage*
	N	*N*		*N*		*N*	
Eersteling	186	63	4.5	225	27.4	90	93.6
Bintje	234	59	4.9	637	<0.03	377	0.8
Desirée	268	74	3.4	636	<0.03	323	23.0
Irene	387	78	4.3	942	<0.03	370	59.7
Prominent	309	84	4.8	499	1.2	360	27.1

4 Haulm pulling systems

With the existing pulling systems, the haulm is pulled in a virtually vertical direction using pulling rollers, or in a virtually horizontal direction using pulling belts or wheels. The pulling efficiency depends on the forward speed, pulling speed and the gripping length over which the stems are being seized. The pulling speed is determined by the peripheral speed of the pulling mechanism and the forward speed. The gripping length is the transport distance between the pulling elements over which the stems are being seized during pulling. The pulling length is the distance across which the gripping point on a stem is displaced by the pulling mechanism.

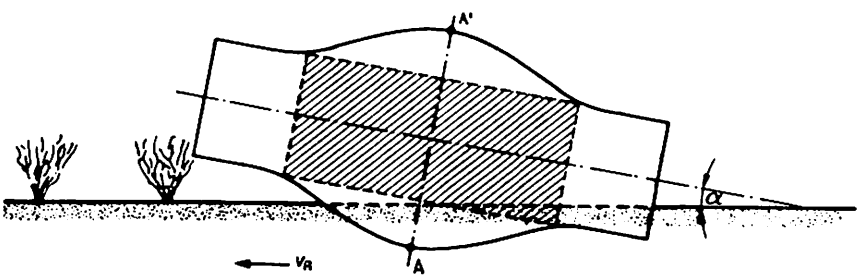
4.1 System using rubber pulling rollers

Figs 3 and 4 show diagrams of the system with rubber pulling rollers, using which the haulm is pulled in a virtually vertical direction. The rollers are inflated with air to a pressure of about 0.5 bar. The conical shape of the rollers at the front produces an opening for the introduction of the stems, followed by the pulling part. The hatched part of fig 3 may be regarded as the gripping area, created because the rolling diameter is greater than the distance between the axes of the rollers. The length of this area is 30 cm and its height, 14 cm (BB' in fig 4). The longitudinal axis in fig 3 forms an angle α with the top edge of the ridge. In practice, this angle is, on average, 8°.

A stem is seized at the beginning of a gripping area and pulled upwards over a distance of 14 cm. During pulling, the machine is advancing. This forward movement imparts continuity to the pulling. Once the point at which the stem is seized has been pulled up 14 cm out of the pulling rollers, the stem or root is at that moment seized between the rollers at a point 14 cm lower. This process is repeated until the gripping area is no longer above the potato plant, or the stem has been pulled. The time, t, during which the gripping area is situated above the plant is

$$t = \frac{\ell \cos \alpha}{100 \; . \; V_R} \quad (s)$$

Fig 3 Side view of the pulling system using inflated rubber rollers.



where ℓ = gripping length, cm;
α = angle between the longitudinal axis of the rollers and the top edge of the ridge, deg;
V_R = forward speed of the machine, m/s

During this time we get at a peripheral speed, V_B of

$$V_B = \frac{N \cdot \pi d}{6.10^3} \quad \text{(m/s)}$$

where N = rotational speed of the rollers, rev/min;
d = diameter of rollers, cm;

and the pulling length, $k = \frac{N \cdot \pi d \cdot \ell . \cos\alpha}{6 \cdot 10^5 \cdot V_R}$

For a practical machine this will come close to a pulling length of $1.74/V_R$ (m) (α= 8°, d = 24 cm, ℓ = 30 cm, N = 467 rev/min). If the forward speed is 5 km/h (1.4 m/s), the pulling length is 1.24 m.

In section 3.2.2, table 10, the pulling out lengths are indicated for three varieties. A comparison of these data with the calculated pulling length shows that the stems can be pulled completely with this system at a speed of 6.69 m/s (25 km/h). As a result of the shape and peripheral speed of the pulling rollers (fig 4), as well as the forward speed, the tubers will remain in the ground, provided there is sufficient soil above the tubers. In a situation where there is not enough soil, the pulling rollers will reach the tubers, which may then be damaged or uncovered.

The pulling rollers are driven via a gearbox from the power take-off. A chopper is fitted in front of the pulling rollers, which chops the haulm and conveys it over the top to the rear.

The stems which remain standing have a length of about 20 cm. The stream of chopped haulm being removed passes over the rollers and thus takes along with it the pulled stems. The whole mass is deposited on the ridge. Depth adjustment of the pulling rollers is achieved by spool-shaped rollers, adjustable in height and fitted behind the pulling rollers. To obtain a good separation between the haulm from different ridges, a divided shredder has been provided at the front of the tractor, which acts only between the ridges, so that the haulm between the ridges does not get knocked down and compacted by the tractor wheels.

In the latest model of this machine, the haulm shredder in front of the tractor is no longer divided. The haulm is struck by the chopper in such a way that the stems on the ridge are left with a length of about 20 cm. In view of this modification, there is no need for the chopper in the pulling mechanism. This latest version has not been included in the tests.

4.2 System using pulling belts
Figs 5 and 6 show dramatically the system with pulling belts which pull the haulm in a virtually horizontal direction. The belts are made of piles of rubber and cord. To prevent the belts from sliding off the pulleys, they have a V-grooved profile on the inside surface. The part over which the stems are being gripped by the belts

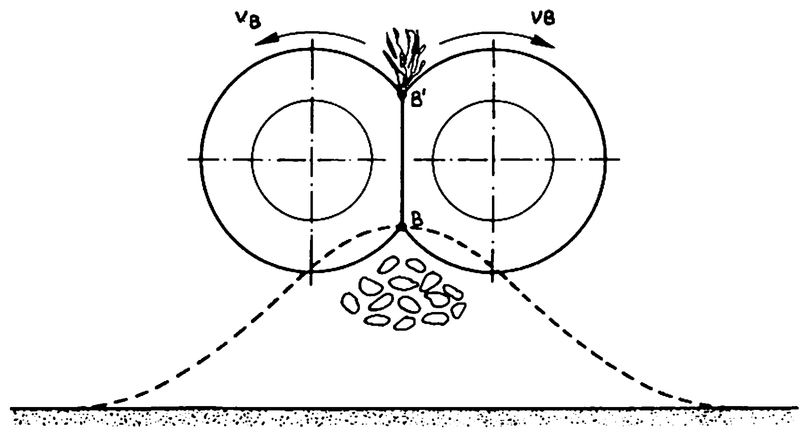


Fig 4 Cross-section AA' (fig 3) through the rubber pulling rollers

Fig 5 Plan view of the pulling system with pulling belts A = driving rollers; B = guide rollers; C-D = gripping length

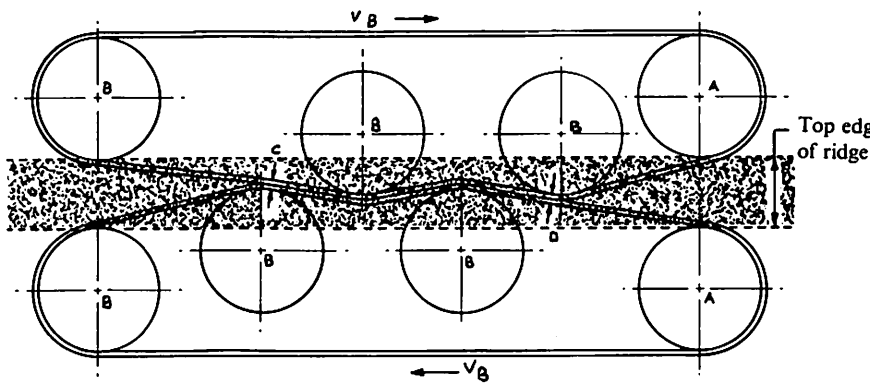
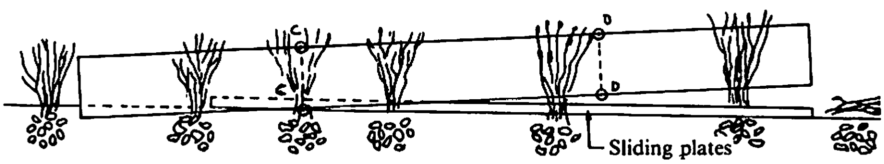


Fig 6 Side view of the pulling system with pulling belts



(C-D in fig 5) is of zig-zag shape. The effect of this is to press the belts against each other and to produce a shaking motion during pulling. A stem is seized at the front at the gripping point C and pulled rearwards over a distance CD. During transport to the rear at a belt speed V_B, the machine has a forward speed V_R. The time during which a stem is wedged between the belts is

$$t = \frac{\ell}{100 \cdot V_B} \quad \text{(s)}$$

where ℓ = gripping length C-D, cm;
V_B = belts speed, m/s.

In this time, the forward displacement, S, of the machine is

$$S = \frac{\ell \cdot V_R}{100 \cdot V_B} \quad \text{(m)}$$

where V_R = forward speed, m/s.

The rearward pulling length k is then

$$k = \frac{\ell}{100} - \frac{\ell \cdot V_R}{100 \cdot V_B} \text{(m)}$$

$$\text{or } k = \frac{\ell (V_B - V_R)}{100 \cdot V_B}$$

In the experimental machine the gripping length ℓ = 53 cm. The pulling belt speed, V_B, can be varied through the power take-off speed and a gearbox on the machine. At a pto speed of 540 rev/min the maximum pulling belt speed is 3.1 m/s. In a practical machine and at the maximum pulling belt speed, the pulling length, k, is then k = (0.53 — 0.17 V_R) m. Using the pulling out lengths indicated in table 10 in section 3.2.2, it will be found that the maximum forward speed for the variety Bintje is 1.6 m/s (5.9 km/h), and for Irene and Prominent 6.4 and 6.8 km/h, respectively. With this system, uncovering of the tubers is prevented by fitting iron plates on the inside edge of the belts and on the bottom edge, which press down on the ground, so that the tubers stay in the soil. The spacing between the plates should be minimized to inhibit tubers from passing through, yet be sufficient to allow the stems to pass. In the event of there being an insufficient amount of soil, or none at all, above the tubers, damage will occur.

The pulling belts are driven by the power take-off of the tractor via a chain case and square gearbox. The chain case has three pto connecting points, so that at a given pto speed of the tractor, three different belt speeds can be obtained. The belt speed can thus be matched to the forward speed. The two pulling belts with the pulleys from one pulling unit are each suspended in a separate frame. The two frames are pivotally attached to each other and the belts are squeezed against each other resiliently at the hinge point. This enables the belts to move apart if a foreign object, such as a stone, is negotiated by the pulling mechanism. The depth is set by ground wheels, adjustable in height, on the chain case, on which the units are mounted. The ground wheels have a spring suspension, so that slight undulations in the ridge are being followed automatically. The sliding plates, which keep the tubers in the ridge, are levelled by means of spool shaped rollers, adjustable in height and fitted to the rear of the pulling mechanism.

A haulm shredder is mounted on the tractor to separate the haulm from the two ridges to either side. In addition, the haulm on the ridges is shortened to a length of about 20 cm.

In the latest model of this machine, the eight small belt idler wheels are replaced by four large ones per unit. The shafts of these wheels can thereby be positioned at a higher position in the frame. This prevents penetration of plant juices and crop material. This modification in design reduces the gripping length from 53 to 45 cm. This version of the machine did not take part in the trials.

4.3 System using pulling wheels

Haulm pullers in which the pulling belts have been replaced by pneumatic tyres and the stems are pulled in a nearly horizontal direction are also being used on farms. Fig 7 shows a diagram of this machine.

The stem is seized at the front at the gripping point C and pulled to the rear over a distance CD. During transport to the rear with a peripheral speed of the tyres V_B, the machine has a forward speed V_R. The same equation, as for the system with pulling belts, can be used for the calculation of the pulling length k to the rear:

$$k = \frac{\ell}{100} - \frac{\ell}{100 \cdot V_B} \cdot V_R$$

With this practical machine, the gripping length, ℓ = 15 cm. The peripheral speed, V_B, of the pulling

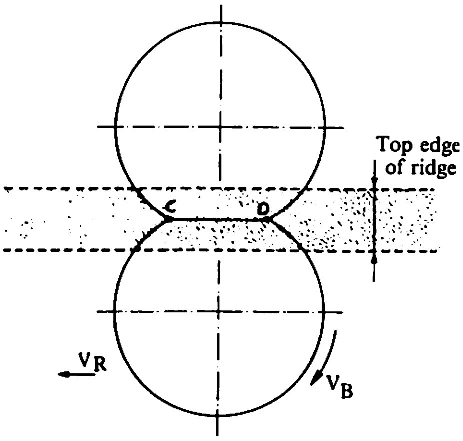


Fig 7 Plan view of the pulling system with pulling wheels

wheels is 8.3 m/s at a pto speed of 540 rev/min. Its pulling length, k, is then:

$$k = 0.15 - 0.02\ V_R$$

Using the pulling out lengths indicated in table 10, section 3.2.2, it will be found that it is not possible to pull all stems with this system. Only stems with a pulling out length of less than 15 cm can be pulled completely. The pulling out length can be reduced by seizing the stems or roots deeper in the ridge. However, this is not possible because the pulling mechanism would then be in contact with the tubers, which would become damaged. To prevent the tubers from being uncovered, high pulling speeds of the stems are adopted, utilizing the inertia of the tubers and the resistance the tubers have to overcome in the soil.

The pulling wheels are pto driven via V-belts and a square gearbox. The position of the pulling wheels in relation to the ridges is adjustable. Depth adjustment is achieved by use of the power lift on the tractor and spool-shaped rollers fitted at the rear of the pulling wheels. A haulm shredder has been mounted on the tractor to separate the haulm from adjacent ridges. In addition, the haulm on the ridges is shortened to a length of about 20 cm.

This machine was not included in the trials.

Conclusions

Potato tubers can be protected from virus infection, introduced into the sap flow of the plant by aphids, by stopping this sap flow by killing or removing the haulm. The haulm may be killed by chemical or heat treatment, or removed by pulling.

The present study investigates the factors affecting the efficiency of mechanical haulm pulling. If the haulm is to be pulled without breaking the stems, the tensile strength of the stems has to be greater than the force needed to pull out the haulm.

Measurements of the tensile strength of the stems show that:

- the tensile strength varies between varieties, if stems of the same thickness are being compared;
- within a given variety, the breaking strength increases with haulm thickness;
- the breaking strength decreases the higher the point at which the stem is being seized;
- the effect of the variety is less clear, if the average breaking strengths are being compared;
- the season has an influence on the breaking strength;
- the variety affects the breaking stress of the stems;
- the stem thickness of three of the seven varieties examined does not affect the breaking stress and with the remaining four varieties the breaking stress decreases with increasing thickness of the stem;

Measurements of the pulling forces show that:

- the very early varieties can be pulled out with a smaller force per plant than the second early, main crop and late varieties;
- the number of stems per plant has no effect on the pulling force per plant;
- the season does not affect the pulling force needed;
- less pulling force is needed at a speed, both in a vertical and horizontal direction of pulling;
- the differences between varieties are more marked at lower pulling speeds;
- with some varieties, horizontal pulling demands a greater force than vertical pulling.

The breaking strength of the stems at a height of 0 cm above ground is such with respect to the pulling forces that there is little chance of breakage, whereas at a height of 10 cm there is a great risk of stem breakage. The length over which the stems have to be displaced in order to achieve a complete separation of the haulm from the tubers in the soil differs between varieties.

When the gripping length of the three pulling systems, as well as the pulling length are being compared, it appears that the gripping length is adequate in the case of the pulling rollers and pulling belts, but inadequate with the pulling wheels.

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