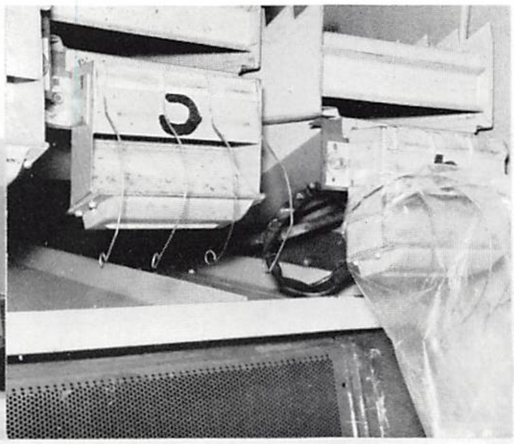
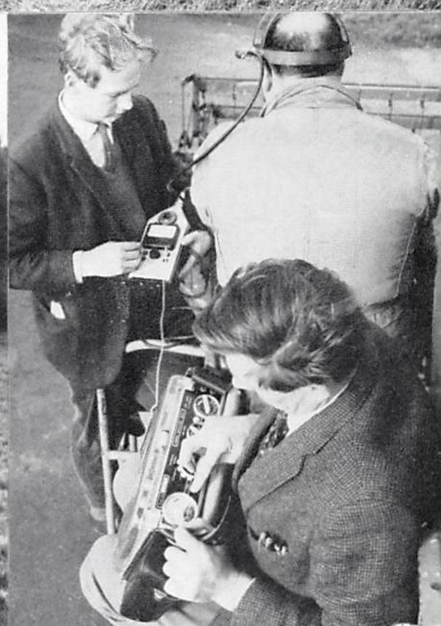
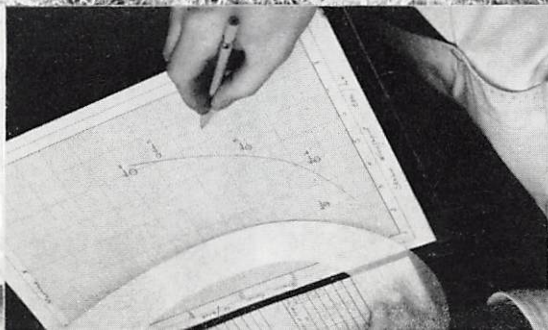
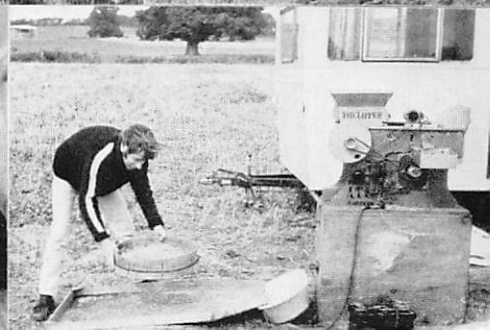
THE AGRICULTURAL ENGINEER

JOURNAL and Proceedings of the INSTITUTION of AGRICULTURAL ENGINEERS ISSN 0308-5732

Volume 34 Spring 1979 No 1

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THE
AGRICULTURAL
ENGINEER

ISSN 0308–5732

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Volume 34 SPRING 1979 No.1

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

Tel: Silsoe 61096

ABC

Price: £2.00 per copy, annual subscription £8.00 (post free in UK)

CONTENTS

Cover: Aspects of combine harvester performance monitoring at NIAE, including the testing of a loss monitor, measurement of dust and noise level at the driver's head position, straw yield determination, moisture estimation and comparison of overall work rate.

Operational research in agricultural engineering

D S Boyce and R W Radley

THE aim of engineering is to provide devices and processes which work and are marketable. In the past much successful engineering was based on experience and intuition supported by trial and error development. Commercial success was dependent on the right economic and social conditions.

Current engineering practice is now more complex and costly. Agricultural machinery and processes, even when the initial ideas have originated on the farm, usually require the support of technology for successful development and marketing. Furthermore, as farming systems have become larger and more complex the problems of establishing an economically worthwhile place for new developments have become much more difficult. It is now important, and in some cases imperative, to have an analytical understanding of a process which relates the inputs and outputs quantitatively and takes into account the properties of the materials concerned. This understanding allows the engineer to predict how the process will operate under different sets of conditions. To do this entirely by direct experimentation would in many cases not be feasible in terms of cost or in time required.

Engineering research has traditionally been concerned with determining the relationship between the process inputs, the properties of the materials involved and the outputs. Relatively simple algebraic equations, mathematical models, have always been extremely important for this purpose. With these simple equations, paper and pencil solutions are usually possible. As engineering technology developed, more complex equations and even sets of equations were derived. In these cases it was often not possible to provide paper and pencil solutions and other techniques, specifically developed for operational research, are required.

In the last two decades computers, with an ability to provide solutions to complex mathematical models, have become readily available and have, as a consequence, become an essential part of much agricultural engineering research. A fundamental advantage of this approach is that it has provided a way of determining the output of a system without always necessarily incurring the expense of producing equipment and carrying out trials. It also enables processes to be studied in which the weather is a major variable. Hay making is an example. Models using historical meteorological data can provide information on the operation not obtainable using other methods.

Operational research generally provides a way of comparing different farm production systems being operated in an optimum way under similar conditions. That is, not only is the most effective system identified but also the way it must be operated to achieve its best performance. Mathematical models and to a lesser extent operational research have become reasonably well established in agricultural engineering research and they are also beginning to be used to provide information on individual farm problems. There is evidence, however, that the agricultural machinery industry is not making the most of these techniques.

To provide examples of the use of mathematical models and operational research in agriculture which would be of interest to those in research, advisory work and industry a joint NCAE/NIAE Operational Research Workshop was held at NCAE, Silsoe, on 20–21 September 1978. Nine papers were presented. One measure of the interest was that more than half of the fifty or more delegates contributed to the discussion. The papers and an account of the discussion has been published and is available from the Scientific Information Department, NIAE, Wrest Park, Silsoe, Bedfordshire MK45 4HS. Two of the papers which should be of interest to many readers are published in this issue of *The Agricultural Engineer*.

L to r: Dr R W Radley, Mr Peter Roberts Head of Systems Analysis Unit, DOE and DOT, Dr. D S Boyce.

One of these papers describes results from a forage conservation simulation model of the effect on the value of a hay crop of each of three different techniques: the use of preservatives to allow safe storage at high moisture contents, increased field drying rates, and barn hay drying. Ten years of weather data from two sites, one more and the other less favourable for haymaking are considered. The reader may care to consider whether it is feasible to carry out field experiments over a number of years to provide such information.

The second paper describes the development of and gives some results from a linear programme to determine the machinery and labour requirements for an arable farm. This original development of a linear programme provides a systematic way of analysing the large amount of information which must be considered when determining a farm's machinery requirements. The reader should consider this information and how *he* would determine the optimum solution.

It is hoped that these two papers describing applications of operational research to agricultural engineering will encourage further developments and uses not only in research but also in farming and industry.

Forthcoming National Conferences

Annual 1979
At The National Agricultural Centre, Stoneleigh, on Tuesday 8 May 1979. One day.
Subject: Efficient Use of Resources – Implications for the Agricultural Engineer.

Autumn 1979
At The National Agricultural Centre, Stoneleigh, on Tuesday 9 October 1979, One day.
Subject: Tillage Equipment Design and Power Requirement in the Eighties.
This Conference is being organised by the Royal Agricultural Society of England, in association with the West Midlands Branch of the Institution.

Spring 1980
At The University of Newcastle, Newcastle-upon-Tyne, on Tuesday 25 March 1980. One day.
Subject: Electronics in Agriculture.
This Conference is supported by the Institution of Electrical Engineers, in association with the Northern Branch of the Institution.

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Details will be published, and registration forms distributed, as and when information is made available.
All enquiries concerning Conferences should be addressed to:
Mrs Edwina J Holden, Conference Secretary, The Institution of Agricultural Engineers, West End Road, Silsoe, Bedford MK45 4DU. Telephone: Silsoe (0525) 61096.

A simulation model of a forage conservation system

A G Dumont, D Parke and D S Boyce

Summary

A MATHEMATICAL model of a forage conservation system has been developed. This has been used to study different aspects of haymaking under weather conditions representing various parts of the country.

The areas of study include:—

(i) The use of propionic acid preservative for storage of hay at high moisture contents.

(ii) The effect on hay value of increasing swath drying rates by mechanical treatment.

(iii) The effect on hay value of barn drying.

The model

A forage conservation system can be represented schematically as shown in fig 1: there is a growing crop and a manager who must decide how to use the labour and machinery available to harvest it. His decisions depend on both the present and forecast weather which may also effect the condition of the crop, its losses and hence its feed value. Fig 1, and the relationships shown, also describe the main elements which are included in a simulation model of the haymaking process which has been developed in the Systems Department at the NIAE[1].

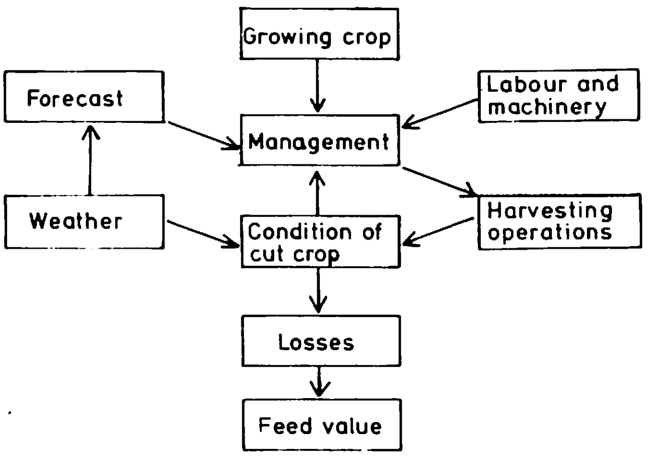


Fig 1 Basis of forage conservation simulation model.

The model uses crop data for a single cut only including the yield, energy, protein and moisture content for each week of the cutting season.

Labour requirement for each operation and total labour available are also input.

After the crop is cut it is affected by the weather directly and indirectly:—

(i) Directly, by the drying action of the air, which is a function of the accumulated vapour pressure deficit (VPD), and by rewetting due to rain. The grass loses digestible dry matter due to respiration after it is cut and the amount lost is proportional to the time in the field at a given moisture content. When the swath gets wet with rain, this prolongs the time in the field as well as introducing more losses due to leaching. These effects are included in the model.

(ii) Indirectly, by the effect of rain which stops work or by the effect of the 'forecast' which is generated in the model from the actual rainfall over a three day period. This 'forecast' is used in decision routines which simulate the manager or decision maker in the haymaking model. The decisions on which jobs to do depend on the 'forecast', and these decisions affect the final value of the crop conserved.

The value of the hay produced from a given area of crop is calculated from its replacement value for purchased feed in a minimum-cost, dairy-cow ration, calculated by a linear programme.

By using the model, different haymaking systems can be compared in economic terms. The model can look at many aspects of haymaking for different climatic regions where weather data are available.

Results using the model

The use of propionic acid preservative

In this example the model has been used to look at the economics of applying propionic acid preservative to hay[2]. This allows the hay to be stored at higher moisture contents without mould development in store, and hence may reduce the time the hay is in the field.

The conditions studied were:—

(i) Use of propionic acid on hay at 4 storage moisture contents; 25, 30, 35 and 40% mcwb, compared with field dried hay at 20% mcwb without acid treatment.

(ii) Use of propionic acid restricted to when rain is forecast, again at the 4 moisture content levels.

(iii) Six start dates for haymaking were used to study the interaction between propionic acid use and start date and its effect on hay value.

(iv) The above for 2 very different weather areas; Plymouth, an area unfavourable for haymaking, and Birmingham (Elmdon airport), an area more favourable.

Figure 2 summarises the results from ten years (1959–1968) haymaking, with the routine use of preservative at the two sites. These results are for a harvest start date of 29 May. This was the best start date, in terms of average hay value, for both sites.

The results show that in many cases the increase in hay value with preservative is similar to the cost of the acid. Thus the use of propionic acid would be made more attractive if either the cost of acid were reduced, or the value of the crop it preserved was increased. The cost of acid could be reduced by restricting its use to swaths at the required moisture content and when the weather forecast is for rain.

Figure 3 shows the results if the use of preservative is restricted to swaths under the greatest risk of rain. For Plymouth this shows a slight increase in net hay value at all moisture contents but at Elmdon tield dried hay still gives the greatest value.

From the results of the study there is little economic advantage from the use of preservative in areas with good natural drying potential. It could increase hay value in situations where, perhaps because of prolonged bad weather, haymaking is started late.

In regions of low drying potential, the use of propionic acid becomes more attractive especially if used selectively, only when rain is forecast. The effective use of the preservative assumes that the moisture content of the cut crop can be accurately monitored and that the precise quantities needed for safe storage can be uniformly applied.

The effect of increased swath drying rates

A second study using the model looked at the value of increasing the drying rate of swaths in the field, probably by mechanical treatments at mowing[3].

The conditions used were:—

(i) Four different drying rates. The lowest corresponding to a cutterbar mower, the second to a mower conditioner, the third to a flail type mower. The fourth was a suggested drying rate, unattainable at present, over twice as fast as a simple, cutterbar mowed and turned swath.

A G Dumont, D Parke and D S Boyce are of the Systems Department, NIAE, Silsoe, Beds.

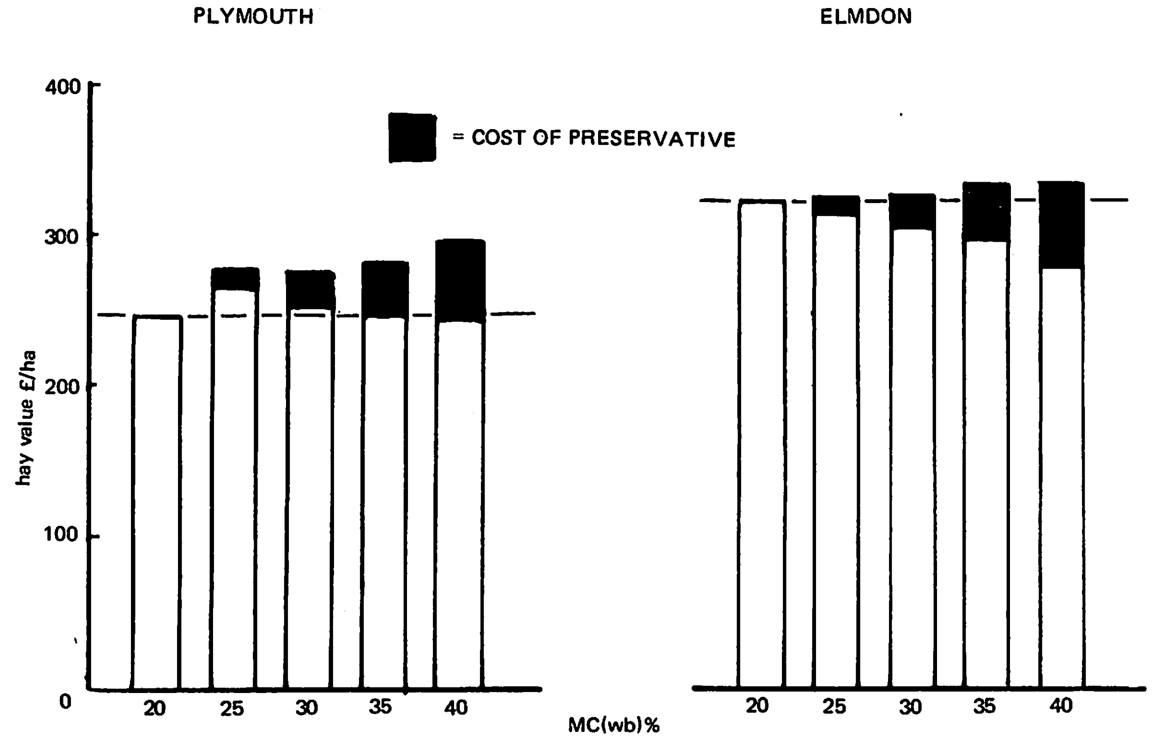
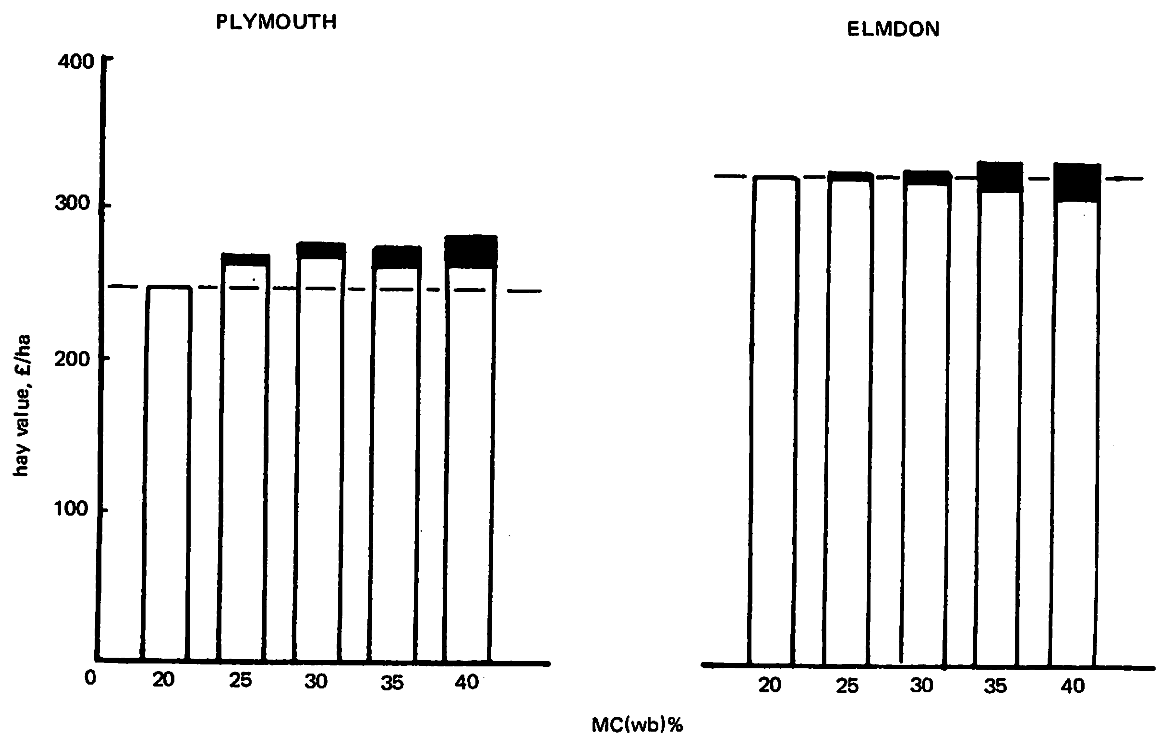


Fig 2 Hay value vs storage moisture content — routine use of preservative.

Fig 3 Hay value vs storage moisture content — restricted use of preservative.



(ii) To look at the effects of different mechanical treatments, loss rates for leaching and tedding were also increased by 2 and 3 times their assumed normal levels.

(iii) For comparison of nutrients preserved, the value of silage made from untedded grass at 75% mcwb was also calculated.

(iv) Two weather sites were used; Plymouth as before and London (Heathrow airport), where the weather is more favourable for haymaking.

Figure 4 summarises the results from this study of ten years haymaking. In general the gains obtained by increasing drying rate exceed the extra loss it may cause but data on the effect of mechanical treatment is very scanty. However, the results are quite insensitive to large variations in the losses assumed, fig 5.

Climatically Plymouth is much less favourable for haymaking than Heathrow. Even at the highest drying rate, the results at Plymouth are only slightly better than those of Heathrow with the slowest drying rate. Silage making is, therefore, likely to be the most effective way to conserve forage at Plymouth. If hay is required however, treatments which increase the drying rate will increase hay value.

At Heathrow, haymaking conserves forage as effectively as silage. Further increases in the field drying rate, above that currently

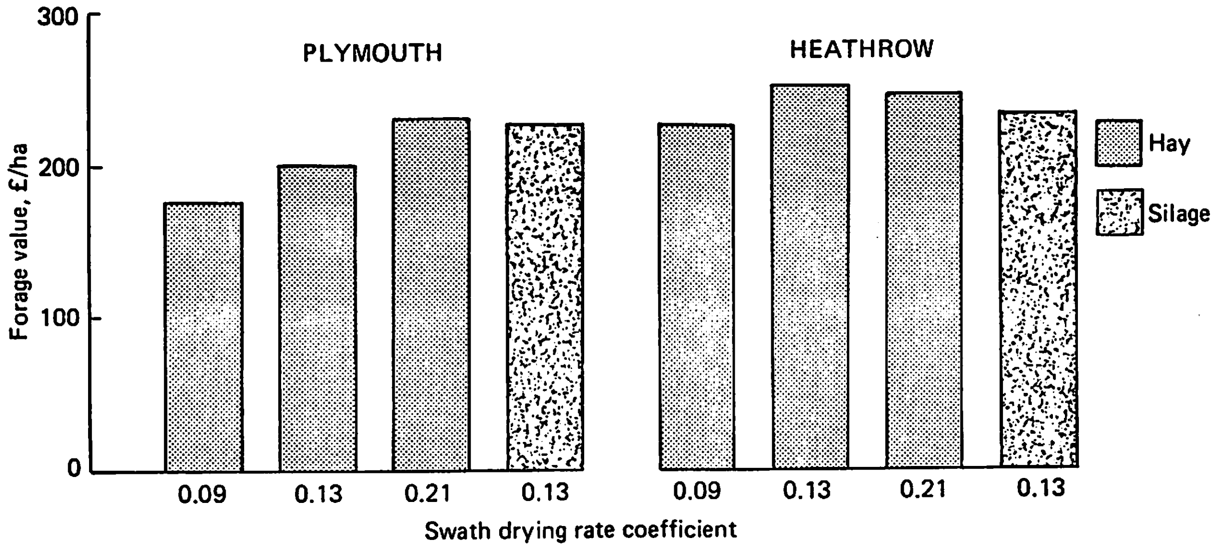
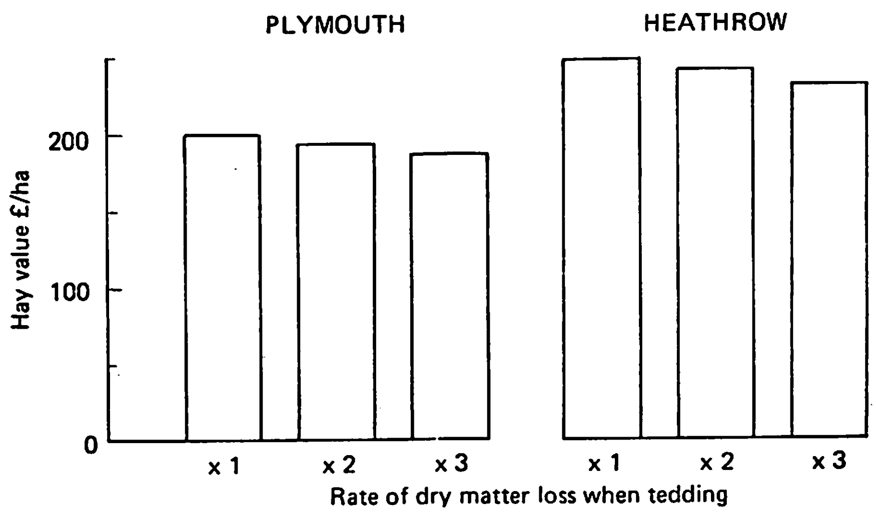


Fig 4 Forage value vs swath drying rate coefficient.

Fig 5 Hay value vs rate of dry matter loss when tedding. Swath drying rate coefficient = 0.13.



available, appear to offer little advantage. It is, however, important that all crop losses are identified and kept as low as possible.

The effect of barn drying on hay value

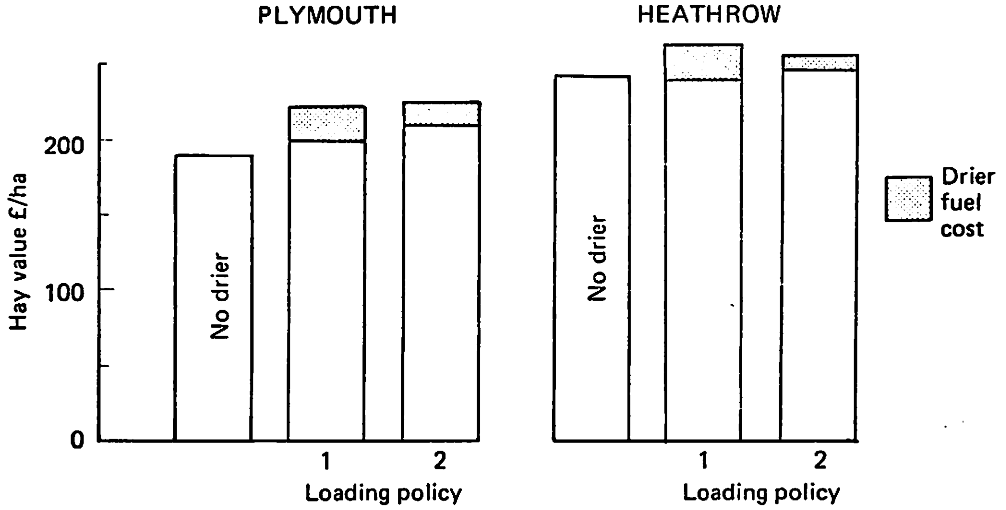
This study looked at the effect on hay value of using a barn hay drier, over a range of weather, crop and management conditions[4].

The conditions used were:—

(i) Two drier capacities; 444 and 1776 m^3.

(ii) Crop densities from 50 to 150 kg DM/m^3 (bulk).

Fig 6 Hay value vs drier loading policy. Crop density in drier = 125 kg DM/m^3. Evaporative efficiency = 1000m^3 air/kg water.



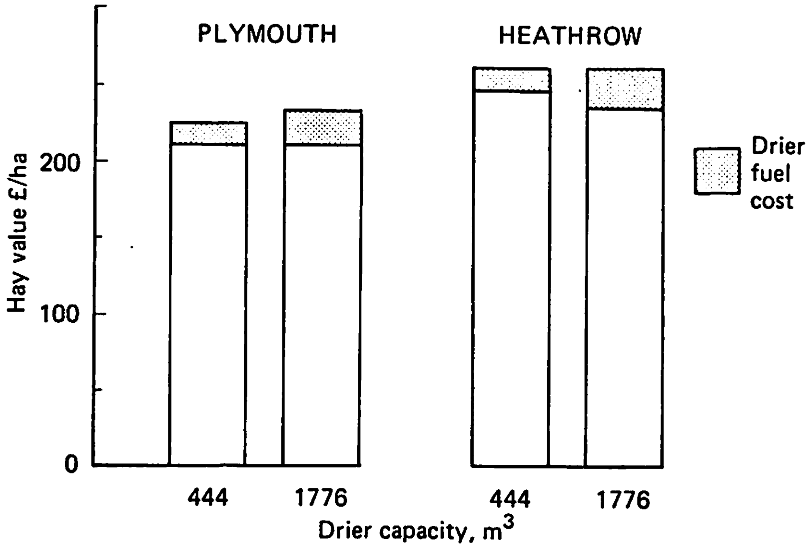
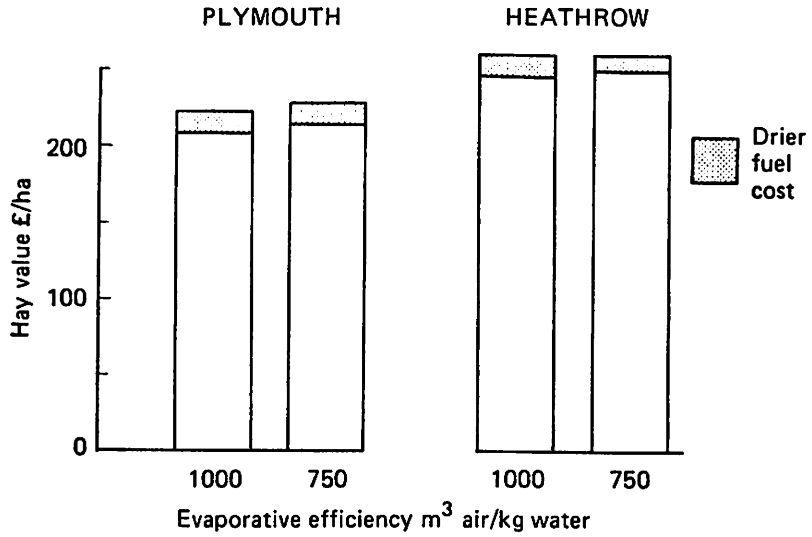


Fig 7 Hay value vs drier capacity. Loading policy 2. Crop density = 125 kg DM/m^3

Fig 8 Hay value vs evaporative efficiency. Loading policy 2. Crop density - 125 kg DM/m^3

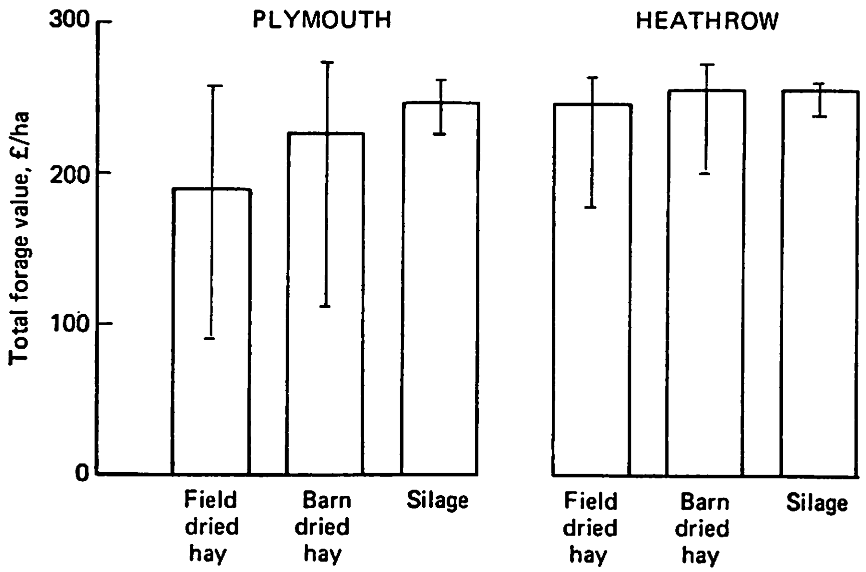


(iii) Two drier management policies:—
   Policy 1: The drier loaded whenever there is crop to dry.
   Policy 2: The drier loaded if there is crop to dry and the forecast is for rain.

With both policies, if there was crop left in the swath after the drier was full, this was field dried down to 20% mcwb and stored.

(iv) Two drying efficiencies were used: 100m^3 air/kg water re-

Fig 9 Forage value vs conservation method. Loading policy 2. Crop density = 125 kg DM/m^3 Evaporative efficiency = 1000m^{3}air/kg water. Capacity = 444m^3



moved, and a proposed rate of 750 m^3 air/kg water removed.

(v) Two weather sites were used; Plymouth and London (Heathrow airport).

Figure 6 shows the mean hay value, with and without the small capacity drier for the different loading policies. The total value of the hay produced with the drier is always greater than the field dried hay. The net values, however, after deducting drier running costs, are only significantly higher at Plymouth. Drier Policy 2 is always the best on average.

Figure 7 shows the effect of a larger capacity drier using just Policy 2. Once again, only at Plymouth was barn drying worthwhile.

Figure 8 shows the effect of increased drying efficiency of the small capacity drier. The only difference from fig 6 is a general increase in net hay value because the drying time is reduced. Barn drying is still only worthwhile in Plymouth, the area with unfavourable weather for haymaking.

The conclusions from the results of this study are that only in areas where, or seasons when, the weather is unfavourable for haymaking will a barn drier increase net hay value. A policy which restricts loading the drier to times when rain is forecast gives the highest net value. The crop density in the drier has little effect on net hay value when the optimum loading policy is used.

Figure 9 summarises the mean, and range, of crop value using different conservation methods at Plymouth and Heathrow. The results suggest that for the best conservation of nutrients and for the smallest year to year variation, silage making is better than field dried hay and as good, if not better, than barn dried hay.

Advantages of the model

These are three examples of the way in which the haymaking simulation model has been used to identify suitable areas of research and development for haymaking at the NIAE. Once developed, such a model can be used to look at any aspect of the haymaking system in any detail that may be required. By changing the crop data used, or even incorporating a weather related growth model, it can be used to look at the effect of haymaking systems with different crops. It can also look at the effect on hay value of feeding the crop to different types of livestock or selling it off the farm.

The development and use of the haymaking model has highlighted the basic information which is required, and sadly lacking, to compare in detail and in a meaningful way the different methods of forage conservation available to a farmer today. Modelling and the sensitivity analysis that can be done goes some way towards overcoming this lack of comprehensive experimental data.

References

1 **Parke, D; Dumont, A G; Boyce, D S.** A mathematical model to study forage conservation methods. *J Br Grassld Soc,* 1975, 33, pp 261-273.

2 **Parke, D; Dumont, A G; Boyce, D S.** The economic benefits of high moisture content hay treated with propionic acid. Dep Note DN/SY/733/1957, NIAE, Silsoe, 1976 (unpubl).

3 **Parke, D; Dumont, A G.** The effect of swath drying rates on hay value. Dep Note DN/SY/823/11007, NIAE, Silsoe, 1977 (unpubl).

4 **Dumont, A G: Parke, D.** Effect of barn drying on hay value. Dep Note DN/SY/868/11007, NIAE, Silsoe, 1978 (unpubl).

Weir Shield and Prize

THE Weir Shield for 1977/8 has been awarded to John Rutherford & Sons Ltd, of Coldstream, and the Weir Prize to their employee, Brian J Turnbull who also attended Galashiels College of Further Education; they received their awards at the Annual Conference at Dunblane on 14 February 1979.

The Weir Shield is awarded annually by the Scottish Branch of the Institution of Agricultural Engineers to the company involved in agricultural engineering who employs the apprentice obtaining the best overall marking in his final examinations (practical and theory) at the end of his indentured period — normally associated with London City and Guilds Course 015 or its equivalent. The apprentice receives the Weir Prize in the form of a tankard, tools, etc, to keep as a memento of his success.

The awards, established in 1973, are named after Jim Weir in recognition of his many years as secretary of the Scottish Branch and subsequently as chairman, during the period of consolidation of the Branch as a viable unit of the Institution.

Planning an arable farm's machinery needs - a linear programming application

E Audsley

Summary

A LINEAR programme of a simple farm is constructed showing the parts needed to describe the constraints on labour, land, tractors and machinery and the sequencing of overlapping operations. The objective function includes the profit from crops, the cost of labour and machinery and a cost due to not carrying out operations at the optimum time. Rotational restrictions can be described either as an overall limit on the crop area or as a penalty cost of not obeying the rotation.

A linear programme which uses a computer program to generate the constraints from a list of input data, is demonstrated on an example arable farm where the cropping is fixed. With the cropping and work rates given, it is optimal to plant the majority of the winter wheat in November and December. The effect of burning rather than baling straw demonstrates the complex interactions between crops that can only become apparent by using linear programming. One less man and tractor are needed, winter wheat is planted in October and potatoes become a more profitable crop than sugar beet. Even so the farm gross margin is reduced by £5/ha.

1 Introduction

With the high cost of modern machinery and labour, it is important not to have more than is really necessary. A large number of different systems are possible, ranging from deep ploughing to direct drilling and from single stage, single row beet harvesting to multi-row, multi-stage. Farms have different types of land, farmers have different cropping plans and the weather varies from year to year. All this means that planning the men and machinery needed by a farm is not easy.

Basically a farmer's objective is to maximise his profit within the constraint of the land available to him, by deciding on the cropping of the land and the men and machinery needed to achieve this. There may be other subsidiary objectives but these are usually only important once a satisfactory profit is assured.

2 A simple example

Suppose I am a farmer and have a simple farm with just two crops. Time is divided into three periods in which I expect a certain amount of time to be available. I hope that in most years there will be more hours than this available but I think it prudent to plan for only this number of hours.

The crops need three operations — harvest, plough and drill. If time is available or if the conditions warrant it, I may carry out other operations, for example spraying for black grass. These are not planned for and if they become necessary, I would have to fit them in with the others. The time needed for each operation is as follows:—

Crop X is harvested in period 1, ploughed in period 2 and drilled in period 3. The time needed to harvest the crop is 0.75 per unit area, but two men are needed making a total of 1.5 per unit area. Crop Y is harvested in period 2, again using two men, ploughed in period 3 and drilled some time later when time is not a constraint. The total crop area must be less than 16 and crop Y is twice as profitable as crop X. The question is: "how do I maximise my profit?"

2.1 A linear programme

I can formulate this problem as a linear programme by considering each period in turn. In period 1 the constraint is that the time needed — 1.5 multiplied by the area of crop X — must be less than the time available which in this case is 20. For period 2, 0.5 multiplied by the area of crop X plus 2.0 multiplied by the area of crop Y must be less than the time available which is 15, and similarly for period 3. There is a further constraint on the total crop area — the area of crop X plus the area of crop Y must be less than 16. The objective is to maximise the profit function — 1.0 multiplied by X plus 2.0 multiplied by Y.

So I get the linear programme:

Constraints

$$1.5\,X \le 20$$
$$0.5\,X + 2.0\,Y \le 15$$
$$0.3\,X + 0.5\,Y \le 5$$
$$X + Y \le 16$$

Objective

$$X + 2\,Y = \text{Profit}$$

Solving this linear programme I will get the optimum profit with:

Area of crop X = 7.1
Area of crop Y = 5.7

Two resources are not fully used; firstly the time available in period 1 in which only 11.7 out of 20 is used and secondly, the total crop area of which only 12.8 of a total of 16 is used. It is thus not profitable with these constraints to crop the whole area.

Farming is of course a variable business. The profitability of crops and the time available to do work are unpredictable. I have decided on the expected level of profit from the two crops, and an expected time available in each period. It is likely that no two farmers will make the same prediction. In addition to the effect of the soil type, a conservative farmer will tend to give a low estimate of the expected profit from a risky crop and a low estimate of the expected time available for work. If I expect 20% more time to be available in each period, ie 24, 18 and 6 respectively, I get the optimum profit with:

Area of crop X = 8.6
Area of crop Y = 6,9

It is likely that perhaps one year out of 10 the conservative farmer will find himself unable to accomplish the required work in the time available because of bad weather. His less conservative colleague who predicted more time available for work may find that the planned work could not be accomplished perhaps three years out of ten.

The other items of data supplied were the rates of work for

Period	Time available	Time needed for unit area					
		Crop X			Crop Y		
		Harvest	Plough	Drill	Harvest	Plough	Drill
1	20	1.5	–	–	–	–	–
2	15	–	0.5	–	2.0	–	–
3	5	–	–	0.3	–	0.5	–
Profit			1.0			2.0	
Total crop area ≤ 16							

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harvesting, ploughing and drilling. The rate of harvesting crop X is not critical to the solution because there is slack time in period 1. The other rates of work will cause small changes to the solution. If any value is in doubt I can change it and quickly obtain another solution to see what the effect of this is.

2.2 The number of men

This is a very simple linear programme. Suppose that instead of the total time available I have the time available per man, where a man costs 15 units of profit and in this case I have a crop area of 160. If the number of men is M then the first three constraints are readily altered to:

$$
\begin{array}{l}
1.5\,X \qquad\qquad \le 20\,M \\
0.5\,X + 2.0\,Y \le 15\,M \\
0.3\,X + 0.5\,Y \le 5\,M
\end{array}
$$

Rewriting this in the usual format of a linear programme with all the variables on the left hand side and including the constraint on the area of land and the revised profit function gives:

$$
\begin{array}{ll}
\textit{Constraints} & 1.5\,X \qquad\qquad - 20\,M \le 0 \\
 & 0.5\,X + 2.0\,Y - 15\,M \le 0 \\
 & 0.3\,X + 0.5\,Y - 5\,M \le 0 \\
 & X + Y \le 160 \\
\textit{Objective} & X + 2\,Y - 15\,M = \text{Profit}
\end{array}
$$

I now have three variables, four constraints and an objective function which can be easily solved. I now get the optimum profit with:

Area of crop X	=	88.9
Area of crop Y	=	71.1
Number of men	=	12.4
Profit	=	44.4

The first constraint has a slack time of 115.6 but all the other constraints are fully used up; that is, I am making full use of the labour available in periods 2 and 3 and the land.

2.3 The cost of labour

Including the cost of labour is one of the major difficulties found in farm planning which can be overcome by using linear programing. How much of the cost of a man should be allocated to crop X and how much to crop Y? Traditional costing exercises allocate the cost of labour as the current wage rate. This can be a misleading way of comparing systems. Systems which save labour are more valuable at critical times of the year, for example, in comparing direct drilling and traditional ploughing. Conversely, if labour is not critical, any saving is irrelevant. For example, when spraying in April/May it may be important to do the job quickly when the conditions are just right, but the saving in labour cost is irrelevant in choosing between systems, as the men do not have to give up a critical job to go spraying.

In this example, if the time needed to harvest crop X can be reduced from 1.5 to 1.2, the optimum profit and cropping is unchanged. The saving in labour is therefore irrelevant. However, if the time needed to harvest crop Y can be reduced from 2.0 to 1.6; the optimum profit is obtained with:

Area of crop X	=	32.0
Area of crop Y	=	128.0
Number of men	=	14.7
Profit	=	67.2

This saving in labour is therefore worth 22.8 because a larger area of the more profitable crop can be grown and instead of less labour being employed, 2.3 more men are employed.

2.4 Machinery

Machinery and tractors are treated in the same way as labour. For example, a harvester for crop X gives rise to an extra constraint. In period 1 the time used for harvesting, 0.75 multiplied by the area of crop X, must be less than the time available, 20 multiplied by the number of harvesters, h_x:

$$0.75\,X \le 20\,h_x$$

Similarly a harvester for crop Y gives rise to a constraint in period 2 of:

$$1\,Y \le 15\,h_y$$

If their annual costs are 3 and 1.5 respectively then the objective becomes:

$$X + 2\,Y - 15\,M - 3\,h_x - 1.5\,h_y = \text{Profit}$$

In this case, since I have only one constraint and one crop for each harvester, it is easy to allocate the cost of the harvester to the crops by traditional methods. Solving this expanded linear programme we get the same solution as previously plus $h_x = 3.3$ and $h_y = 4.7$.

The tractor-time needed for this farm at foot of page.

This is similar to the labour needed by the crops except that the harvester for crop X is self-propelled so that only one tractor is needed. The necessary constraints are therefore:

$$
\begin{array}{l}
0.75\,X \qquad\qquad \le 20\,T \\
0.5\,X + 2.0\,Y \le 15\,T \\
0.3\,X + 0.5\,Y \le 5\,T
\end{array}
$$

where T is the number of tractors. Assuming the cost of the tractor is 1.5, the optimum solution is unchanged and 12.4 tractors are needed. Here again, the cost of the tractors has been allocated to the different crops by the linear programme.

2.5 Crop rotation

So far I have been concerned only with the men, machinery and land available. Crop rotations also have to be taken into account in planning. In this simple example there is little scope for introducing complex crop rotations, so as an example I will consider what happens if crop Y can only be grown one year in three and crop X must be grown the rest of the time. This means that the area of crop Y must be less than half the area of crop X. Expressed algebraically:

$$2\,Y \le X$$

More complex rotations will need correspondingly more complex constraints to describe them.

The overall linear programme is now:

$$
\begin{array}{lll}
\textit{Constraints} & 1.5\,X \qquad\qquad - 20\,M \le 0 & \rbrace \\
 & 0.5\,X + 2.0\,Y - 15\,M \le 0 & \text{labour} \\
 & 0.3\,X + 0.5\,Y - 5\,M \le 0 & \rbrace \\
 & X + Y \le 160 & - \text{land} \\
 & 0.75\,X - 20h_x \le 0 & \text{harvesters} \\
 & 1.0\,Y - 15\,h_y \le 0 & \\
 & 0.75\,X - 20\,T \le 0 & \rbrace \\
 & 0.5\,X + 2.0\,Y - 15\,T \le 0 & \text{tractors} \\
 & 0.3\,X + 0.5\,Y - 5\,T \le 0 & \rbrace \\
 & -X + 2\,Y \le 0 & - \text{rotation} \\
\textit{Objective} & 1\,X + 2\,Y - 15\,M - 3\,h_x - 1.5\,h_y - 1.5\,T = \text{Profit} &
\end{array}
$$

This linear programme has 10 constraints and 6 decision variables and would be difficult to solve by hand even using special LP techniques, but on the computer it takes a negligible time to solve. The solution is:

Area of crop X	=	106.7
Area of crop Y	=	53.3
Number of men	=	11.7
Crop X harvesters	=	4.0
Crop Y harvesters	=	3.6
Number of tractors	=	11.7

2.6 Sensitivity

With a linear programme it is important to know how sensitive the results are to the input data. With this problem it is easy to change the data and obtain new solutions. Table I lists the effect of changing some of the data. If the time to harvest crop Y is 2.5, then the optimum area of crop Y is 45.7, a reduced crop area. However, if the time to harvest crop Y is less than 2.0, it doesn't alter the solution so I needn't worry if I think I have overestimated the harvesting time.

3 Multi-period and overlapping operations

So far, I have only considered the case where one job occupies one period and there is no overlapping between jobs. In practice, a job can cover several periods and overlaps with others. Continuing with

Period	Time available per tractor	Time needed per unit area					
		Crop X			Crop Y		
		Harvest	Plough	Drill	Harvest	Plough	Drill
1	20	0.75	–	–	–	–	–
2	15	–	0.5	–	2.0	–	–
3	5	–	–	0.3	–	0.5	–

Table I Sensitivity analysis

	Present	New value	Crop X	Crop Y
Original data	–	–	106.7	53.3
Harvest crop X	1.5	2.0	No change	
		1.0	No change	
Harvest crop Y	2.0	2.5	114.3	45.7
		1.5	No change	
Plough	0.5	0.7	144.5	15.5
		0.6	No change	
		0.3	No change	
Drill crop X	0.3	0.4	No change	
		0.2	121.9	38.1
Profit crop X	1.0	1.4	139.0	21.0

the example, suppose I divide the time available into six periods, fig 1. Crop X can be harvested in either of the first two periods but the second period gives a slightly lower profit margin because there is a timeliness cost eg shedding losses with cereals. Ploughing can take place at any time from period 2 onwards. Crop Y is planted after crop X in period 6. Crop Y can be harvested in any of the periods from 2 to 4 but in this case the profit margin increases the longer the crop is left, for example, sugar beet. Crop X is planted after crop Y and must be planted either in period 4 or 5. There will be a lower crop yield from crop X planted in period 5 rather than period 4. Period 5 has the least amount of time available. This is the quite common situation of a conflict of priorities. It is best to drill crop X in period 4, but it is best to leave crop Y as long as possible before harvesting and in any case, there is little time to do either. What is best?

The labour constraints are much the same as previously (variable names are defined in fig 1).

Period

$$
\begin{array}{ll}
1 & 1.5\,xh_1 \leq 10 \\
2 & 1.5\,xh_2 + 0.5\,xp_1 + 2.0\,yh_1 \leq 10 \\
3 & 0.5\,xp_2 + 2.0\,yh_2 + 0.5\,yp_1 \leq 8 \\
4 & 0.5\,xp_3 + 2.0\,yh_3 + 0.5\,yp_2 + 0.3\,px_1 \leq 7 \\
5 & 0.5\,xp_4 + 0.5\,yp_3 + 0.3\,xd_2 \leq 5 \\
6 & 0.6\,yd_1 \leq 10
\end{array}
$$

I need to introduce a new type of constraint to describe the sequencing of operations. If I wish to plough an area of crop X in period 2, I must previously have harvested the area. Expressed as a constraint this is:

$$xp_1 \leq xh_1 + xh_2$$

Thereafter, for ploughing crop X we only need one constraint, that the total area of crop X ploughed must be less than the total area of crop X harvested.

$$xp_1 + xp_2 + xp_3 + xp_4 \leq xh_1 + xh_2$$

In this case the first constraint is automatically satisfied if the second constraint is satisfied. Therefore, the first constraint is redundant.

In similar fashion the area of crop Y drilled must be less than the area of crop X ploughed; the area of crop Y harvested must be less than the area of crop X drilled; ploughing of crop Y must follow the harvesting of crop Y; etc. Altogether eight constraints are needed to describe the sequencing in this case, as follows:

$$
\begin{array}{lll}
xp_1 + xp_2 + xp_3 + xp_4 & \leq xh_1 + xh_2 & -a \\
yd_1 & \leq xp_1 + xp_2 + xp_3 + xp_4 & \\
yh_1 + yh_2 + yh_3 & \leq yd_1 & \\
yp_1 & \leq yh_1 + yh_2 & \\
yp_1 + yp_2 + yp_3 & \leq yh_1 + yh_2 + yh_3 & -b \\
xd_1 & \leq yp_1 + yp_2 & \\
xd_1 + xd_2 & \leq yp_1 + yp_2 + yp_3 &
\end{array}
$$

In addition I need the constraint on the total area of land.

$$xh_1 + xh_2 + yh_1 + yh_2 + yh_3 \leq 16$$

And the profit objective function:

$$1.0\,xh_1 + 0.9\,xh_2 + 1.8\,yh_1 + 2.0\,yh_2 + 2.2\,yh_3 - 0.1\,xd_2 = \text{Profit}$$

I have imposed the restriction that crop Y is drilled following crop X, crop X is drilled following crop Y. In other words crop Y follows crop X, as night follows day. To introduce a rotation constraint, I use a transfer variable t, which allows crop X to follow crop X or crop Y to follow crop Y. Suppose I only allow crop X to follow crop X and that to do so would mean that the profit from crop X is reduced by 0.1. In this case, crop constraints a and b of the previous section become:

$$
\begin{array}{ll}
xp_1 + xp_2 + xp_3 + xp_4 + t & \leq xh_1 + xh_2 \\
yp_1 & \leq yh_1 + yh_2 + t \\
yp_1 + yp_2 + yp_3 & \leq yh_1 + yh_2 + yh_3 + t
\end{array}
$$

and 0.1 t is subtracted from the profit function.

A similar alteration to these constraints would allow crop Y to follow crop Y if necessary.

I could also introduce rotational constraints as before that the area of crop Y must be only half the area of crop X and constraints on machines and tractors.

3.1 Solutions

No 1 in table II is the solution to this problem. Crop Y is more profitable than crop X, so the linear programme has rejected the transfer variable and planted the same area of both crops. It has decided it is most profitable to delay harvesting crop Y and therefore drilling crop X, as much as possible. Ploughing following crop X, is done as soon as possible.

If there had been no difference in the profit margin of harvesting crop Y in periods, 2, 3 and 4, the optimum is solution 2. In this case crop Y is harvested as soon as possible to enable all crop X to be drilled in period 4 and ploughing following crop X is delayed until period 5.

If crop X is worth 2.2 the transfer variable comes into operation, solution 3. In this instance it is optimum to plant 10 of crop X and 6 of crop Y.

4 A full-scale farm

The same basic principles can be applied to planning a farm with a large number of crops and machines.

However, writing out the constraints on such a farm can be very difficult, so I have computerised the process. The input data are presented as a number of tables and a computer programme interprets these tables to produce the necessary linear programming constraints. In addition to simplifying the input so it can be understood by non-experts, this also has the advantage of reducing the scope for errors in the input.

Fig 1 Overlapping operations and timeliness costs.

Period	Time available	Time needed for unit area														
		Crop X							Crop Y						Crop X	
		Harvest		Plough				Drill	Harvest			Plough			Drill	
1	10	1.5														
2	10		1.5	0.5					2.0							
3	8				0.5					2.0		0.5				
4	7					0.5					2.0		0.5		0.3	
5	5						0.5							0.5		0.3
6	10							0.6								
Profit		1.0								2.2						
Timeliness cost		0.0	0.1					0.0	0.4	0.2	0.0				0.0	0.1
Variable names		xh_1	xh_2	xp_1	xp_2	xp_3	xp_4	yd_1	yh_1	yh_2	yh_3	yp_1	yp_2	yp_3	xd_1	xd_2

Table II Solutions from linear programme with overlapping operations and timeliness costs
(1—data as given, 2—equal value for crop Y harvest, 3—value of crop X=2.2)

	Operation	Period	Solution No		
			1	2	3
Area of crop X	Harvested	1	6.7	6.7	6.7
		2	1.3	1.3	1.3
	Ploughed	2	8.0	1.2	6.0
		3	–	–	–
		4	–	–	–
		5	–	6.8	–
Area of crop Y	Drilled	6	8.0	8.0	6.0
	Harvested	2	1.2	3.7	–
		3	3.6	2.5	3.1
		4	3.2	1.8	2.9
	Ploughed	3	1.8	6.2	3.8
		4	–	1.8	–
		5	6.2	–	6.2
Area of crop X	Drilled	4	1.8	8.0	3.8
		5	6.2	–	6.2

The output from the linear programme is produced in a tabular fashion which is easier to read than the standard linear programming output. It should therefore be possible for an advisor, without expert knowledge of linear programming, to use this linear programme as a planning tool for farmers. It would determine the men and machinery needed for a particular cropping plan; the effect of a cropping change on the farmer's workplan; the effect of changing the machinery, for example purchasing a larger capacity machine, on the optimum cropping and workplan; or the crops which are most profitable. From the results and a sensitivity analysis, the advisor can tell the farmer whether a proposed change is likely to be profitable and the problems that will be created (or solved) by the change.

4.1 An example of advising a farmer

A farmer has decided on a cropping plan and asks for advice on whether this is a good cropping plan and on the number of men and machinery he will need for his plan. The farm is 400 ha and the proposed cropping plan is 50 ha spring barley, 150 ha winter wheat, 50 ha potatoes, 50 ha sugar beet, 50 ha oilseed rape and 50 ha spring beans.

4.1.1 Men

The annual cost of a man is £3500 and at least four men will be needed to make an adequate gang size.

4.1.2 Tractors

The tractors can be either 40, 60 or 80 kW. Assuming they are kept for five years and that the interest rate is 9% and the inflation rate is 10%, the capital cost must be multiplied by 0.168 so that the annual costs are £803, £1309, £1814 respectively[1].

This takes into account the repair and maintenance cost, final resale value, and the current inflation and interest rates.

4.1.3 Ploughs

The farmer is prepared to have either a three-furrow or four-furrow deep plough but is not prepared to consider any other type of primary cultivators such as a rotary digger even though an economic study[2] has shown them to be very worthwhile. Their annual costs are £518 and £637 respectively.

4.1.4 Other machinery

The other machinery needed to harvest and plant crops is listed in table III.

4.1.5 Work periods

The year, or a part of the year, can be divided into up to 15 periods. In this case the relevant part is from late July to May and the time is divided into 13 periods. Table IV lists the estimated number of workable hours in each period[3].

4.1.6 Rates of work

The operations on each crop are divided into harvesting, ploughing and drilling. Harvesting and drilling are particular to each crop but ploughing is common to the different types of crop. Crops are divided into three types: 1—cereal crops, such as wheat and barley; 2—non-root break crops, oilseed rape or beans; 3—root crops, potatoes or sugar beet.

Type 3 crops will normally be ploughed deeper than the others and so will have a slower ploughing rate of work. For rotations it is assumed that type 1 crops will normally follow type 2 or 3 crops and there will be a penalty cost of £42/ha if they follow type 1 crops.

Table V lists the data for all the crops.

Spring barley is crop type 1 and there are 50 ha. Combine harvesting can take place from early August to early September at a rate of 0.45 h/ha. Two tractors are needed ie 0.9 h/ha. It is possible to specify a particular size but in this case any size can be used. With one man on the combine and one man on each tractor a total of 1.35 h/ha of labour is needed. The gross margin is £192/ha in early August allowing for some drying, £196/ha in late August and £186/ha in early September allowing for shedding losses.

Spring barley can be drilled in February, March or early April. Drilling uses the conventional drill and takes 0.68 h/ha. Any size of tractor can be used and allowing time for rolling and harrowing the seed bed a total of 4.0 h/ha are needed. Likewise 4.0 h/ha of labour are needed. The best time to plant the barley is in February. It is estimated that planting this crop in March will result in a loss of £10/ha and in early April, a loss of £20/ha.

Table VI lists the rates of work for primary cultivation.

4.2 Machinery

Table VII lists the optimum solutions for a number of cases. With the original data, solution 1 lists the optimum men and machinery. By far the most profitable crop is sugar beet and the optimum farm gross margin is £245/ha. Labour is fully used from early August to November and 80% used in March. The optimum work plan drills 79 ha of winter wheat in November and 14.1 ha in winter.

The small amounts of machinery such as 0.1 three furrow ploughs are of little consequence. Fixing this at zero and forcing the solution to have one 60 kW tractor has little effect on the solution and no effect on farm gross margin, solution 2. Forcing the farm to have one sugar beet harvester has a slight effect on numerical values although the characteristics of the solution are unchanged, solution 3. To obtain a full whole number solution would take a lot of computer time and would be very little different from the present solution. It is therefore much more useful to examine the effect of the data on the continuous solution rather than attempt to obtain a few whole number solutions. It is possible to input a machinery complement and obtain the optimum cropping with these.

Table III Machinery cost

	Annual cost £	Capital cost £
Combine harvester	3664	21565
Potato harvester	1324	7000
Beet harvester	1135	6000
Cereal drill	866	3049
Potato planter	339	1500
Precision drill	426	1500
Baler	387	2000
Tractor 40 kW	803	4780
60 kW	1309	7792
80 kW	1814	10798
Plough 3-furrow	518	2297
4-furrow	637	2825

Table IV Workable hours available

	Workable hours
Late July	81
Early August	77
Late August	74
Early September	73
Late September	72
October	129
November	79
Winter	135
February	100
March	127
Early April	69
Late April	72
Early May	151

Table V Crop data

Crop	*Operation*	*Time*	*Machine*	*h/ha*	*Tractor h/ha*	*Labour h/ha*	*Gross Margin £/ha*
Spring barley	Harvest	Early August	Combine	0.45	0.90	1.35	192
		Late August					196
		Early September					186
	Drill	February	Drill	0.68	4.00	4.00	0
		March					–10
		Early April					–20
Winter wheat	Harvest	Late August	Combine	0.49	0.98	1.47	256
		Early September					246
		Late September					236
	Drill	Late September	Drill	0.68	4.00	4.00	0
		October					–15
		November					–30
		Winter					–45
Straw	Harvest	Late July	Baler	0.82	2.75	2.75	33
		Early August					33
		Late August					33
		Early September					30
		Late September					27
Potatoes	Harvest	Early August	Potato	5.00	20.00	20.00	608
		Late August	Harvester				
		Early September					
		Late September					
		October					
	Drill	March	Potato	4.40	8.40	8.40	0
		Early April	Planter				–10
		Late April					–50
Sugar beet	Harvest	October	Beet	2.50	10.00	10.00	563
		November	Harvester				591
		Winter					598
	Drill	March	Precision	2.00	5.20	7.20	0
		Early April	Drill				–10
		Late April					–30
Oilseed rape	Harvest	Late July	Combine	1.56	3.12	4.68	309
		Early August					
	Drill	Late August	Drill	0.68	2.16	2.16	0
		Early September					0
		Late September					–10
Spring beans	Harvest	Early August	Combine	0.87	1.74	2.61	193
		Late August					
	Drill	February	Drill	0.68	2.16	2.16	0
		March					–10

Table VI Ploughing rates of work

Tractor	Plough	Rate of work, h/ha
40 kW	3 furrow	1.43
60 kW	3 furrow	1.03
80 kW	4 furrow	0.81

4.2.1 Effect of changes to the data

In December and January, 22.4 ha sugar beet are harvested, 14.1 ha winter wheat are planted and 134 ha are ploughed. This is a lot of planned work for the winter period because of the 135 hours available per man. Solution 4 is optimum when only 25 hours are available in December and January.

Sugar beet is by far the most profitable crop. This could partly be due to the gross margin that has been specified but also the harvesting rate of 2.5 h/ha. If the rate of work is only 4.5 h/ha, solution 5 is the optimum with a farm gross margin of £232/ha.

Wheat, barley and spring beans, even then, are £326/ha worse than sugar beet. Baling straw is a slow operation. If instead the straw is burnt, which needs very little labour, the optimum is solution 6. Even though less men and tractors are needed, it still has a lower farm gross margin, though this may be balanced by a saving in cost due to the beneficial effects of straw burning, which are not taken into account here. The best crop is now potatoes because labour is free to harvest them. In addition winter wheat can be planted earlier – only 9.3 ha in November.

Table VII Men and machinery needed for different conditions

Solution	1	2	3	4	5	6	7
Men	6.2	6.2	5.8	6.6	7.4	6.5	6 or 7
Tractor 40 kW	4.8	4.2	3.9	4.5	4.8	3.5	3 or 4
60 kW	0.4	1.0	1.0	1.0	1.4	1.4	1
80 kW	1.0	1.0	1.0	1.2	1.2	1.5	2
3-furrow plough	0.1	–	–	–	–	–	–
4-furrow plough	0.8	0.8	0.9	1.1	1.0	0.9	2
Combine harvester	1.0	1.0	1.0	1.0	0.9	0.9	1
Potato harvester	0.7	0.7	0.7	0.7	0.7	0.9	1
Beet harvester	0.4	0.4	1.0	0.8	1.4	1.4	1
Drill	0.7	0.7	0.8	0.7	0.8	0.8	1
Potato planter	0.8	0.8	0.8	0.8	0.8	0.8	1
Precision drill	0.5	0.5	0.4	0.5	0.8	0.8	1
Baler	0.5	0.5	0.4	0.5	0.8	–	–
Farm gross margin, £/ha	245	245	243	240	232	227	–

4.3 Optimum cropping

4.3.1 Six men

The optimum cropping policy using the men and machinery listed in column 7 table VII is given in solution 7, table VIII. This assumes that straw is burnt and only 25 hours are available for work in December/January. Oilseed rape is considered a better use for the combine harvester than wheat and barley in early August. Spring barley is preferred to winter wheat.

Reducing the gross margin for oilseed rape from £309 to £259 with the same men and machinery, solution 8 merely exchanges winter wheat for oilseed rape and adjusts the work plan correspondingly.

Increasing the time needed for harvesting sugar beet to 4.5 h/ha, with the same men and machinery, solution 9, reduces the area of sugar beet, potatoes and winter wheat and increases the area of spring barley. The farm gross margin is £34/ha less. Looked at another way, with 50 ha of sugar beet harvested at 4.5 h/ha, it is worth £13,600 p.a. to be able to reduce that to 2.5 h/ha and increase your sugar beet area by 50%.

If straw is baled, solution 10, no winter wheat and less potatoes can be grown. The major crop is spring barley, mostly drilled in February. However the farm gross margin is only £9/ha less.

Table VIII Optimum cropping using machinery listed in column 7 of table VII, ha

	7	8	9	10	11	12	13
Spring barley	121.5	115.1	166.7	175.2	24.9	57.3	91.8
Winter wheat	40.7	84.9	27.4	0.0	137.3	128.7	70.4
Potatoes	60.9	60.9	52.8	48.1	60.9	60.9	60.9
Sugar beet	75.6	75.6	51.8	75.6	75.6	51.8	75.6
Oilseed rape	101.3	63.5	101.3	101.1	101.3	101.3	101.3
Spring beans	0	0	0	0	0	0	0
Farm gross margin	263	248	229	254	265	237	266

4.3.2 Seven men

If seven men and tractors are used rather than six, the optimum cropping policy is solution 11, table VIII. The only difference between this solution and that with six men is that 100 ha are planted with winter wheat rather than spring barley. Although this is worth £60/ha more, it only makes £800 difference to the whole farm.

If the time needed to harvest sugar beet is 4.5 h/ha, solution 12, (cf solution 9), this again means that 100 ha more winter wheat rather than spring barley can be planted, but in this case, the farm is £3200 better off.

If straw is baled, solution 13 (cf. solution 10), 70 ha more wheat and the maximum area of potatoes, within the capacity of the machinery, can be planted rather than spring barley. The farm is now £4800 better off.

4.3.3 Choice of cropping

To summarise these results the area of sugar beet and potatoes should be the maximum that the machinery can manage in the time available. This depends both on the rate of work for harvesting and the hours available for work at harvesting time. In practice, it would also be limited by quota.

The area of oilseed rape depends on its gross margin, but at £309/ha, 101.3 ha should be grown. With a lower gross margin, less should be grown.

The remaining area should be made up of winter wheat and spring barley. The area of each depends on the labour available, after other jobs, to harvest them and drill winter wheat. Thus baling straw means that more spring barley should be grown.

It is most profitable to employ seven rather than six men.

5 Conclusions

Linear programming can be used to look at the effect of different work rates and cropping on the men and machinery needed on a farm. Changes in work rates can cause some surprising effects, such as was shown with the drilling of winter wheat. By using a linear programme, farmers can see the likely effect of changes of cropping or machinery which would be too complex to determine otherwise. Although straw burning needs one less man and tractor and enables most of the winter wheat to be planted in October, it is not in fact more profitable.

By providing a simple input format which can be converted automatically by computer into a linear programme and then printed out in an understandable format, this planning technique can be put within the reach of any farmer.

At the same time this is also a useful tool for the research worker. He can rapidly discover whether a new technique — for example the rotary digger which provides a faster work rate at a higher cost, is economical. Conversely he can discover what work rate or cost is economical.

6 References

1 **Audsley, E; Wheeler, J.** The annual cost of machinery calculated using actual cash flows. *J agric Engng Res,* 1978, *23*

2 **Audsley, E; Dumont, S; Boyce, D S.** An economic comparison of methods of cultivating and planting cereals, sugar beet and potatoes and their interaction with harvesting, timeliness and available labour by linear programming. *J agric Engng Res,* 1978

3 **Nix, J.** *Farm Management Pocketbook*, Wye College, 1976

Annual General Meeting, Annual Conference and Annual Luncheon of the Institution

Date: 8 May 1979.
Venue: National Agricultural Centre, Stoneleigh, Kenilworth, Warwicks.
10 00 h **Annual General Meeting** (members only)
10 30 h Coffee
10 55 h **Annual Conference**
Subject: Efficient Use of Resources: Implications for the Agricultural Engineer.
The Chairman Opens the Conference
Chairman: T C D Manby, Head of Machine Division, National Institute of Agricultural Engineering, Silsoe.
11 00 h Paper 1. Design considerations for Optimum Performance and Durability.
J V Fox, Managing Director, Bomford and Evershed Ltd.
11 30 h Paper 2. Efficient Use of Energy in Agriculture and Horticulture: the paper considers U K energy prospects in relation to reserves and consumption; the effect of increases in energy prices on crop production costs, and the responses of agriculture and horticulture in terms of conservation measures and uses of new sources of energy that are already being made and some other, more speculative ones, that might come about.
D J White, Ministry of Agriculture, Fisheries and Food.
12 00 h Paper 3. Trained Engineers: improved performance depends to a considerable extent on the effective use of their expertise at all levels in the industry. Does the educational system meet the demand, and are the employers making good use of their material?
B A May, Head of School, National College of Agricultural Engineering, Silsoe.
12 45 h ANNUAL LUNCHEON, Guest of Honour: W F Raymond, Deputy Chief Scientist, Agriculture and Horticulture, Ministry of Agriculture, Fisheries and Food.
14 30 h Paper 4. Field Machinery and Labour: a farmer reviews the relative merits of single ownership, group ownership, and the role of contractors in equipment utilisation.
M Nicholson, Bicester.
15 00 h Paper 5. Processing Plant and By-products; this Speaker will describe Kockums grass/whole crop cereals/beet pulp drying and processing plant, and outline their straw utilisation plans.
I Bjurenvall, Kockums Construction AB, Sweden.
15 30 h Discussion Closure.
16 15 h Tea.

Registration forms for members with registered addresses in the UK and Eire are enclosed with this Journal. Members abroad, and any other persons, requiring further details or registration forms should write to the Conference Secretary:
Mrs Edwina J Holden, Conference Secretary,
The Institution of Agricultural Engineers, West End Road, Silsoe, Bedford MK45 4DU.

Hardfacing soil-engaging equipment

M A Moore, V A McLees and F S King

1 Introduction

With the increasing cost of replacement components, and of the labour to replace them, consumers are continually seeking ways of extending equipment life. For soil engaging equipment in the agricultural industry one potential means is to apply a weld deposit of hard material to wearing components. This may be particularly attractive on the farm since most farm workshops have the necessary welding equipment and worn out components can also be rebuilt.

In previous work[1] we established the relative wear performance of a selection of commercially available hardfacing materials using completely coated paraboloidal specimens. This work showed that complete coverage by hardfacing for components worn in a stony soil was uneconomic. Thus the objectives of the work we now report were to investigate the wear of components partly covered with hardfacing and to assess the effects of soil type on relative wear life of hardfaced components.

2 Hardfacing the specimens and measuring wear and soil properties

2.1 Hardfacing the specimens

The specimens for field wear trials were 50 mm x 100 mm x 12 mm steel blocks specially designed for these experiments, and 75 mm x 360 mm x 11.25 mm curved steel plate chisel plough points. For the first trials 0.40%C steel blocks (BS 970:080A40) were hardfaced with weld beads of a nominally 3.5%C, 33%Cr material in the form of 10 swg flux coated electrodes. Figure 1 shows the 24 weld bead patterns for the first trials. For the second trials additional samples of patterns 1D, 2D and 3A, fig 1 were produced and the chisel plough points were hardfaced with the patterns shown in fig 2. Treatment A consisted of pattern 1 on the front face of the point, treatment B of pattern 2 on the front and pattern 3 on the back, and treatment C of pattern 2 on the front and pattern 4 on the back. For all of the hardfaced specimens we measured the mass of hardfacing added, the length of electrode used and the time taken for applying it.

After hardfacing we heat treated the 0.40% steel blocks and some plain blocks by oil quenching from 840°C and tempering to a Vickers hardness of between 4500 and 5000 MN/m^2. Some 0.37%C, 3% Ni/Cr/Mo control blocks (BS 970:817M40) were also heat treated to a Vickers hardness of about 5000 MN/m^2. It was necessary to preheat the chisel plough points to about 300°C prior to welding, since they were 0.55%C, 1.75%Si, 0.9%Mn steel. After welding the base material had a Vickers hardness of about 2700 MN/m^2 and the hardfacing deposit a hardness of about 6500 MN/m^2.

2.2 Wear measurements

The test sites were on fields of stubble or consolidated soil at Preston, Herts: Sandy, Beds; Wrest Park, Beds, and Lilley, Herts.

The soils at these sites had the general textural classifications of; clay/clay loam with high flint content, with a moisture content of 27.4 percent dry base, a sandy loam containing ironstone with a moisture content of 2.84 percent dry base; clay containing small flints with a moisture content of 5.6 percent dry base; sandy clay loam with a moisture content of 23.3 percent dry base, and clay with high flint content with a moisture content of 15.1 percent dry base. The first four sites were used for testing the hardfaced blocks and the last site for testing the chisel plough points.

A randomised split block layout was used to test the steel blocks and, for the chisel ploughs, a Latin square plan for five points arranged on a leading chevron. In the randomised split block layout each specimen was run-in for 100 m then run for four lengths of 100 m, one in each of four areas on the site, and in a random sequence. The specimens completed six runs, but specimens in the second set of trials at the third and fifth sites were run for an additional three runs. In the Latin square tests the chisel plough points completed five runs, each with a random arrangement of the points on the chevron, of 1000 m after an initial run-in of 100 m.

Martin A Moore is at Fulmer Research, Stoke Poges, Slough, Bucks, and V A McLees and F S King from NIAE, Silsoe, Beds.

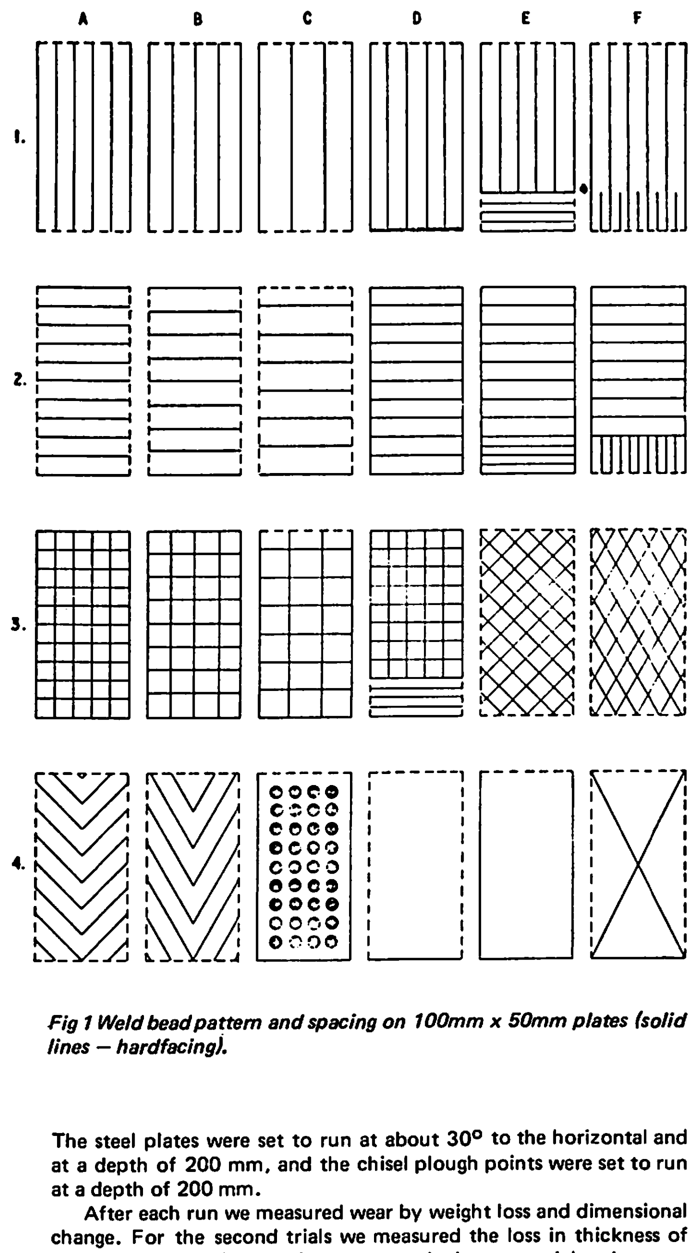


Fig 1 Weld bead pattern and spacing on 100mm x 50mm plates (solid lines — hardfacing).

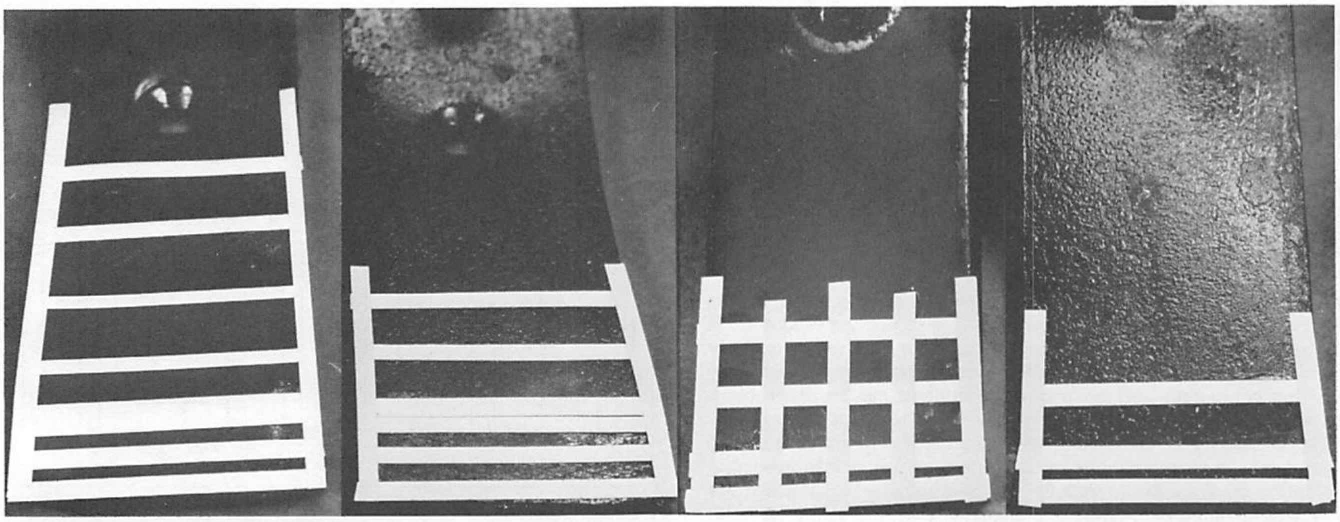
The steel plates were set to run at about 30° to the horizontal and at a depth of 200 mm, and the chisel plough points were set to run at a depth of 200 mm.

After each run we measured wear by weight loss and dimensional change. For the second trials we measured the loss in thickness of the steel plates at four stations; two on the base material and two on the weld beads. And for the chisel plough points we measured the loss in length of the points. This data is shown as relative wear resistance, weight loss of the control specimen divided by weight loss of test specimen, in tables I and II. Table III shows weight and length loss for the chisel plough points and the significance of difference of the means from the analysis of variance of the Latin square experiments .

2.3 Soil properties

On each day of testing we took soil moisture content samples from the working depth of 200 mm. And on the final day of testing at each site we measured bulk density with an γ-ray probe and cohesive strength with a 125 mm diameter shearbox, and took soil samples for mechanical analyses.

In addition to the soil property measurements we carried out a limited investigation of the draft force for a plain steel plate[2] and one with a transverse weld bead pattern, 2D in fig 1. The test sites were near Milbrook, Bedfordshire, and near Wrest Park, Bedfordshire. Soil at the first site was a sandy clay loam with 78% sand and at the second site a clay with 64% clay. A six dynamometer frame rig



Pattern 1-20mm spacing. *Pattern 2-15mm spacing.* *Pattern 3-15mm spacing.* *Pattern 4-15mm spacing.*
Fig 2 Hardfacing weld bead patterns for the chisel plough points.

sensed the draft force, sampling it 400 times over each run, and runs were made at forward speeds of 0.3, 1.7 and 3.3 m/s.

3 The effect on wear of weld bead pattern and spacing

3.1 Weld bead pattern

Spacings for the weld bead patterns of specimens 1A, 1D, 2A, 2D, 3A, 3E, 4A, 4B, and 4C, fig 1, were the same, 10 mm. And thus comparison of their performance should indicate any effects due to pattern. For these patterns there was no simple relationship between wear resistance, tables I and II, and area of the specimen covered by

Table I Relative wear resistances estimated by weight loss for steel plates worn in a clay/clay loam with high flint content at Preston, Herts. (% Standard deviation)

Specimen No.	Relative wear resistance	
	By weight loss	
1A	1.37	(16)
1B	1.13	(14)
1C	1.01	(6)
1D	1.35	(17)
1E	1.26	(8)
1F	1.18	(8)
2A	1.36	(6)
2B	1.68	(15)
2C	1.51	(6)
2D	1.68	(12)
2E	1.51	(8)
2F	1.63	(10)
3A	1.69	(8)
3B	1.42	(13)
3C	1.98	(7)
3D	1.23	(15)
3E	1.22	(4)
3F	1.36	(15)
4A	1.44	(7)
4B	1.21	(9)
4C	1.72	(8)
4D	0.87	(12)
4E	1.08	(9)
4F	1.09	(11)
B S 970 steels		
0.40%C	0.80	(12)
0.37%C 3% Ni/Cr/Mo	1.00	

hardfacing. For example, 3A and 4C have similar wear resistances but 3A has nearly three times as much weld bead as 4C, whereas 4B and 4C have similar total lengths of weld bead but different wear resistances. Comparison of specimens 1A, 1D, 1E and 1F of specimens 2A, 2D, 2E and 2F and of specimens 3A and 3D also shows that additional coverage in the form of fill-in beads at the leading edge of the specimens had little effect on wear resistance.

By far the greatest effect on wear resistance appears to be orientation of the weld beads with respect to the direction of wear. This is shown by comparison of specimens in groups 1, 2, 3 and 4. The most marked differences were between specimens with longitudinal weld beads and those with transverse weld beads. The effect of pattern on wear resistance is attributed to disruption of soil flow, probably by the formation of stationary soil bodies on the specimen surface as shown in fig 3. Further evidence of such a mechanism was provided by the appearance of the specimens after wear and thickness loss data. For specimens in groups 2 and 3 there was only a small loss in thickness of the steel base plates and very little evidence of sliding damage to the base material between weld beads: the damage was expected from the stationary soil under high load. Such stationary soil bodies will shorten the abrasive particle contact distance and thus tend to reduce the amount of wear.

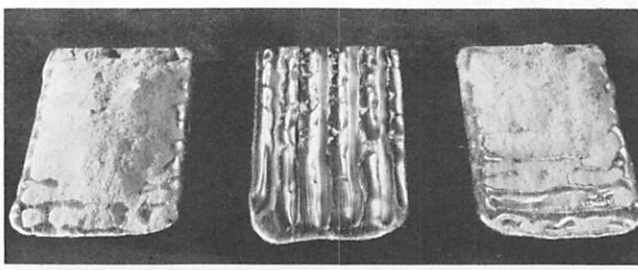


Fig 3 Soil build up on patterned plates after wear at Wrest Park, Silsoe. Patterns 3A, 1D and 2D are from left to right.

In spite of the differences in wear resistance calculated from weight loss data, there was vey little visual difference in the loss of length of the hardfaced steel plates and control plates worn in the same soil. The weld beads were more severely attacked at the tip than at the rear of the plates. We found similar effects for the chisel plough points, table III. For these the difference in the amount of wear of points at different positions in the chevron pattern was large, so only differences of 30% or more in the means are significant in the statistical analysis. However, hardfacing did influence the tip geometry of the points, fig 4. The addition of hardfacing to the point face increased the wear 'land' on the underside, treatment A in fig 4, but the addition of hardfacing to both front and rear of the point, treatment B in fig 4, gave a wear profile similar to that of the untreated points. This behaviour indicates that hardfacing the point faces does have some influence on the wear rate at the tip, at least in the early stages of wear. But once a stable profile forms the wear rate may be about the same[3], so the effect of differences in profile on overall life is probably small. This is supported by the data for

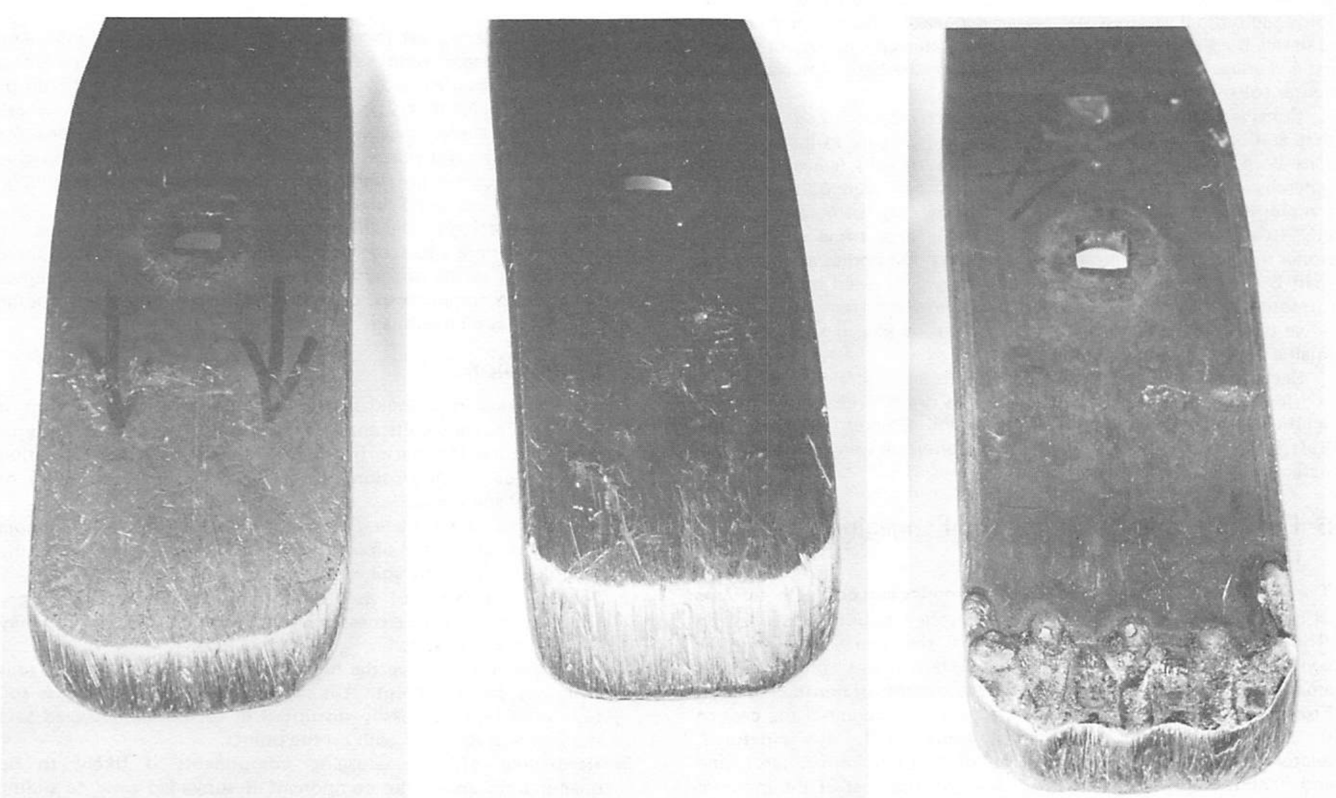
Table II Mean relative wear resistances, from weight loss, of hardface patterned and plain steel plates. Standard errors bracketed, worn in different soils.

Location	Sandy, Beds. TL194484	Wrest Park, Beds. TL088358	TL088356	Lilley, Herts. TL152243	TL147237	Preston, Herts. TL179233
Soil type & stones	Loamy sand, ironstone	Sandy clay loam		Clay, small flint		Clay/clay loam large flint
Distance Run m	0 – 2400	0 – 2400	2400 – 3600	0 – 2400	2400 – 3600	0 – 2400
Pattern 1 D	1.64 (0.07)	1.37 (0.02)	1.09 (0.02)	1.17 (0.06)	1.15 (0.04)	1.35 (0.05)
Pattern 2 D	2.48 (0.10)	1.53 (0.10)	1.57 (0.03)	1.31 (0.02)	1.25 (0.09)	1.68 (0.13)
Pattern 3 A	4.48 (0.06)	2.04 (0.13)	1.41 (0.02)	1.39 (0.11)	1.25 (0.02)	1.69 (0.08)
Plain Control 0.10%C	1.14 (0.04)	0.93 (0.04)	1.05 (0.07)	1.01 (0.01)	1.09 (0.03)	0.80 (0.03)
Plain Control 0.37%C 3% Ni/Cr/Mo	1.00	1.00	1.00	1.00	1.00	1.00

Table III Mean weight loss and loss in length per 1000 m run for plain and hardfaced chisel plough points

	Untreated control		Treatment A hardfaced		Treatment B hardfaced		Treatment C hardfaced		Analysis of variance
Total distance run, m	Wt loss g/100m	Length loss mm/100m	Wt loss g/100m	Length loss mm/100m	Wt loss g/100m	Length loss mm/100m	Wt loss g/100m	Length loss mm/100m	Significance test
5000	17.8		18.6						NSD
		2.0		2.1					NSD
	21.3		19.3						NSD
		2.1		1.2					SD
	30.3				22.4		22.4		SD
		2.9				2.5		2.6	NSD
	32.5				21.3		24.8		SD
		3.3				2.2		2.1	NSD
10000	19.4		17.3						NSD
		1.3		1.4					NSD
	18.7		17.6						NSD
		1.8		1.6					NSD

Fig 4 Comparison of wear 'land' on the underside of chisel plough points
(a) Untreated *(b) Treatment A.* *(c) Treatment B.*



steel plates in the extended trials at Wrest Park and Lilley, table II. There is an overall tendency for the relative wear resistance by weight loss to decrease as wear on the point increases.

3.2 Weld bead spacing

For groups 1, 2 and 3 of the steel plates, fig 1 specimens A, B, and C have similar patterns with spacings of 10, 12.5 and 16.5 mm respectively. The effect of spacing on wear resistance appears to be two-fold. First, the data for group 1, table I, show wear resistance decreases as the spacing increases. We attribute this to decreasing the proportion of surface covered by hardfacing. Second, the data for groups 2 and 3 show spacing may influence the ability of a pattern to disrupt soil flow — too close a spacing will not encourage the formation of stationary soil bodies, whereas increasing the spacing decreases the proportion of coverage. Thus for patterns with transverse weld beads there may be an optimum spacing, probably between 12.5 and 16.5 mm.

4 The effect of soil type

As expected the wear rate of hardfaced steel plates varied considerably with changes in soil type and mechanical properties. Wear was higher in the strong soils with high stone content[4]; for example the mean weight loss on pattern 2D was about 11 g/400 m run in the clay with flints at Lilley and about 4 g/400 m run in the sandy clay loam at Wrest Park. Normally, for materials like high carbon high alloy hardfacing, the wear resistance relative to 0.37%C, 3% Ni Cr Mo steel is highest in non-cohesive soils with flints and lowest in cohesive soils with ironstone[1,4]. The reason for this is that under high loads ironstone tends to shatter and become a very efficient abrasive, whereas under low loads flint deteriorates by plastic flow and is an inefficient abrasive. These effects are more marked for materials such as hardfacings that contain very hard carbides than for the homogeneous steel control material. However, for the hardfaced steel plates, our data, table II, did not follow this general trend. We suggest the reason for this is that the soil type affects the ability of the hardfacing pattern to disrupt soil flow.

Observation of the plates after wear showed that the 2D pattern had static penetration damage to the base material between the weld beads when worn in the clay soils at Lilley and Preston. When worn in the lighter soils at Sandy and Wrest Park the same pattern had some sliding damage to the base material near the front of the plates, and sliding damage had caused scalloping of the base material between the weld beads at Wrest Park. However, the weld beads themselves were severely worn, almost down to the level of the base material, in the clay soils but only slightly worn in the lighter soils. The loss in thickness measurements, also show that the ratio of wear on the weld beads to wear on the base material is somewhat higher for the clay at Lilley than the sandy clay loam at Wrest Park. For the longitudinal pattern 1D, wear can easily occur on the base material by sliding. And for the crosshatch pattern, 3A, there was little damage to either the weld beads or the base material in the lighter soils.

Consideration of soil/soil and soil/steel interactions[5], indicates that stationary soil bodies might form more easily in less cohesive soils because the ratio soil/soil cohesion to soil/steel adhesion is generally lower. Our observation of stationary soil bodies on the transverse weld bead patterns in the sandy clay loam soil supports this. In addition in strong soils with high large stone content the stones might easily penetrate any stationary soil bodies and wear the weld beads. The critical spacing and height of weld beads for the formation of stationary soil bodies may also vary for different soils — we expect the soil to plate adhesion to increase if the spacing is small and weld bead height large.

Because soil/soil coefficient of friction and soil/steel coefficient of friction are similar for most soils[5] the draft force should not be significantly influenced by stationary soil adhered to tines. Our draft force measurements showed that transverse weld beads did not increase the draft force significantly.

5 Economics of hardfacing soil engaging components

The main problem in analysing the economics and cost effectiveness of hardfacing treatments is in estimating the labour cost, deposition efficiency plant running costs, etc. In this work we timed the application of each pattern for the steel plates, measured the amount of weld put on the job and the amount of hardfacing used. From this information and the wear data we calculated the cost of the wear losses for each specimen, Appendix I. This is defined, relative to the 0.4%C steel, as the cost of the material for, hardfacing and heat treating the specimen divided by the cost of the material for and heat treating a similar specimen of 0.4%C steel and by the wear resistance of the hardfaced specimen relative to 0.4%C steel. In practice, one large variable is the cost of the hardfacing material in rod form. The variation in price with respect to the material we used, for material of similar composition expected to produce deposits of similar structure, was from 50% less to 40% more. Thus we have calculated the cost of the wear losses using two hardfacing prices, one being double the other, and this data is shown in table IV.

Table IV Relative cost of the wear losses for two consumable costs

Specimen No.	Upper and lower limits for cost of wear losses							
	Clay / Clay loam		Loamy sand		Sandy clay loam		Clay	
1A	1.6	2.2						
1B	1.8	2.5						
1C	1.8	2.4						
1D	1.8	2.5	1.5	2.1	1.8	2.5	2.1	2.9
1E	1.9	2.8						
1F	2.1	3.1						
2A	1.5	2.1						
2B	1.1	1.4						
2C	1.1	1.5						
2D	1.5	2.2	1.7	2.5	1.6	2.4	1.9	2.8
2E	1.7	2.5						
2F	1.6	2.4						
3A	2.0	3.1	0.8	1.3	1.7	2.6	2.4	3.8
3B	2.1	3.1						
3C	1.2	1.7						
3D	2.9	4.4						
3E	2.1	3.1						
3F	1.8	2.6						
4A	1.4	2.0						
4B	1.5	2.0						
4C	1.1	1.5						
4D	1.1	1.2						
4E	1.3	1.7						
4F	1.3	1.7						
0.4%C steel	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

The costs are highest for the stronger, more aggressive soils. And only in the loamy sand soil at Sandy was there a direct cost advantage for hardfacing by the 3A pattern. Even so it should be remembered that our trials showed little or no advantage on length loss so the cost advantage would only appear if a component was subject to wear on a plane surface. Even for the most favourable estimate of decrease in length loss by hardfacing the chisel plough points there would be no direct cost advantage for hardfacing.

Thus hardfacing is only likely to be economic in cases where the component is only subjected to sliding wear on its face, when there is a significant saving on the high cost of downtime in replacing or repairing worn components, or when the cost of labour for welding is written off as an overhead.

6 Conclusions

1. The orientation of weld beads with respect to the direction of soil flow has a significant effect on wear. Weld bead patterns incorporating transverse beads reduce wear. It is suggested that this is due to disruption of soil flow and the formation of stationary soil bodies.
2. Weld beads of hardfacing on the front and rear faces of simple tine points and chisel plough points have very little effect on the rate of length loss by soil wear.
3. Spacing and height of weld beads may be critical if stationary soil bodies form, but these have not been quantified and may vary from soil to soil.
4. Hardfaced points have the highest wear resistance in weak soils with low stone content. It is suggested that this is because soil flow may be more easily disrupted in such soils and lead to a reduction in the wear path on the points.
5. Hardfacing of soil engaging components is likely to be uneconomic unless the component is subjected only to sliding

wear on its face, there is a significant saving on the high cost of downtime, or the labour for welding is written off as an overhead.

7 References

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Acknowledgement

The authors are grateful to the Director, NIAE, and the ARC for permission to publish and to members of Soil Dynamics Section, NIAE for carrying out the draft force measurements.

Appendix I

Example calculation of cost of wear losses.

The following calculation is an example of those carried out to assess the relative cost of the wear losses. The costs used are those pertaining in 1975.

Cost of 1 m² of 10 mm thick 0.4%C steel plate plus heat treatment		£54
Cost of hardfacing rods to cover 1 m² of plate with pattern 1A	@ 25 p / rod	£46
	@ 50 p / rod	£92
Cost of labour including overheads – @ £2.20/h – and electricity for hardfacing		£23
Total cost for hardfacing, with pattern 1A, and heat treating 1 m² of 0.4%C steel	@ 25 p / rod	£123
	@ 50 p / rod	£169
Relative wear life, with respect to heat treated 0.4%C steel of pattern 1A in clay/clay loam soil		1.4
Thus relative cost of wear losses	@ 25 p / rod 123/(54x1.4) =	1.6
	@ 50 p / rod 169/(54x1.4) =	2.2

Cost of using hardfacing components would be increased by a factor of 1.6 and 2.2.

New BSRAE Association

A NEW ASSOCIATION is to be launched jointly at the National Institute of Agricultural Engineering (NIAE) and the Scottish Institute of Agricultural Engineering (SIAE) by the British Society for Research in Agricultural Engineering (BSRAE).

The scheme is directed particularly at farmers, growers, contractors, agricultural engineers, manufacturers and dealers. Participation will, however, also be encouraged from associated industries, advisers, educationalists and other research workers.

Main objectives of the scheme will be

- to extend the results of research, design and development work of the Institutes to those actively engaged in farm mechanisation and the application of engineering to Agriculture and Horticulture.
- to promote the direct exchange of information,
- to provide guidance in the planning of research and development, and
- hasten the acceptance of new ideas and equipment.

Starting date will be 1 September 1979 and full details will be available in April. The first members' day will be 18 October 1979 when research work and testing on tractors will be displayed, and the Committee of the Association will be formed.

Further details may be obtained from Mr I J A Gunn, Secretary, BSRAE, NIAE, Wrest Park, Silsoe, Bedford MK45 4HS.

Waste heat recovery in piggeries

J L Woods

THE report describes the construction of a heat exchanger using relatively inexpensive and corrosion resistant materials, and a computer simulation of the heat exchanger performance in a typical pig finishing house. Laboratory experiments on the heat exchanger performance indicated an effectiveness of the order 40%. The computer simulation uses this value, together with hourly weather data for one year and typical data for a finishing house. The simulation calculates the reduction in additional feed costs due to house temperatures below the critical, when a heat exchanger system is incorporated. It is shown how the value taken for minimum ventilation rate determines the economic viability and need for heat recovery.

Only a part of the energy consumed by the pig is incorporated into the animal; the remainder leaves the pig in three forms. One fraction goes to heating the surroundings, another is lost in the evaporation of moisture and the third leaves in the faeces and urine. The following table illustrates the gross energy inputs and outputs for a typical fattening pig fed at three times maintenance.

Table 1 Energy inputs and outputs for a 60 kg fattening pig

	Dry matter (kg/day)	Energy (MJ/day)	(Watts)
Feed input	2.24	27.9	322
Heat loss	–	8.3	96
Evaporation loss	–	6.2	72
Faeces and urine loss	0.35	5.6	65

To maximise the efficiency of the overall production system, these energy outputs should be utilised. Of the numerous possibilities for utilising the energy, the most obvious is the conservation of the heat output from the pig to maintain the piggery temperature. This paper is largely concerned with the necessity for and feasibility of a heat recovery system, to transfer the heat in the outgoing stale air to the incoming fresh air.

Heat exchanger design

Figure 1 illustrates the basic principle of a heat recovery system. The heat from the pigs is lost through both the structure and ventilation. The structural loss can be controlled by insulation. To reduce the ventilation heat loss for a given ventilation rate requires a heat exchanger, through which both streams must pass. The function of this device is to transfer heat from the stale air to the fresh air, whilst keeping them separate.

HEAT RECOVERY SYSTEM

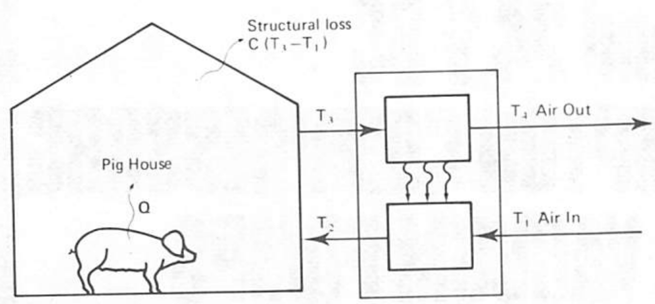

Fig 1 Heat recovery system

Heat Exchanger Effectiveness $= \left(\frac{T_2 - T_1}{T_3 - T_1} \right)$

In the piggery situation, the particular requirements for a heat exchanger are a resistance to corrosion and a facility for cleaning. These requirements, together with that of cost, are the constraints that gave rise to a design based on plastics and wood. The basic structure of the heat exchanger is illustrated in fig 2. The surface through which the heat is transferred and which separates the flows

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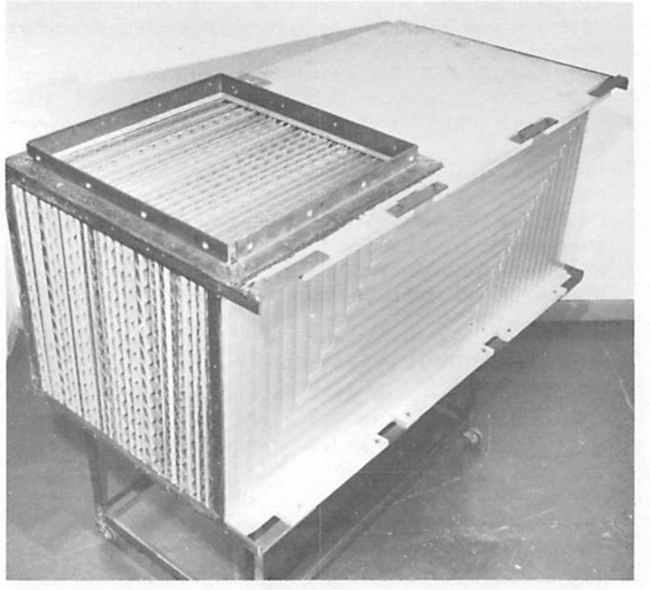


Low temperature heat exchanger showing paths for exhaust (warm) air and incoming (cool) air.

is polythene sheet. The sheets are held at a fixed spacing by means of corrugated pvc sheeting. Alternate sheets are cut and laid in a zig-zag pattern in this particular design. It achieves a central region in the heat exchanger where the flows are in opposite directions. This is termed a counter-flow region and is the most effective for maximising heat transfer. The alternate layers of polythene and corrugated sheet are contained in a plywood box. A plywood pressure plate is used to compact the layers.

The materials used in the design are not subject to corrosion and the design is such that the elements can be quickly dismantled for cleaning, checking or replacement. The design does not involve any sophisticated manufacturing techniques. The effectiveness of the heat exchanger is 40% at the design flow rate of 0.5 m^3/sec. The effectiveness of the device increases slightly as the flow rate is reduced.

Overall system design

To recover the heat in the exhaust air, the input and output streams must both pass through the heat exchanger.

To achieve this and ensure a good air distribution, the system illustrated in fig 3 is proposed. The heat exchanger is modified to the simple cross flow type. This simplifies manufacture and cleaning, and as will be shown later, a slight decrease in effectiveness is not critical. The air is distributed by a perforated polythene duct, the technique of distributing the holes to get an even distribution is well documented. The exhaust side of the heat exchanger, where grease and dust will be deposited, can be washed by a sprinkler system. Condensation will aid this process. To wash the inlet side, the exchanger could be turned appropriately. Access to the heat exchanger elements is from the side, which does not require any other dismantling of the system.

The system appears to offer a technological solution, the question now becomes one of economics.

Economic feasibility of heat recovery

The need for a heat recovery system depends on the amount of heat being lost in the ventilating air. This is proportional to the volume flow rate and the difference between inside and outside temperatures. In the winter situation, which is the one of interest for heat recovery, the ventilation rate is minimised. The lower limit

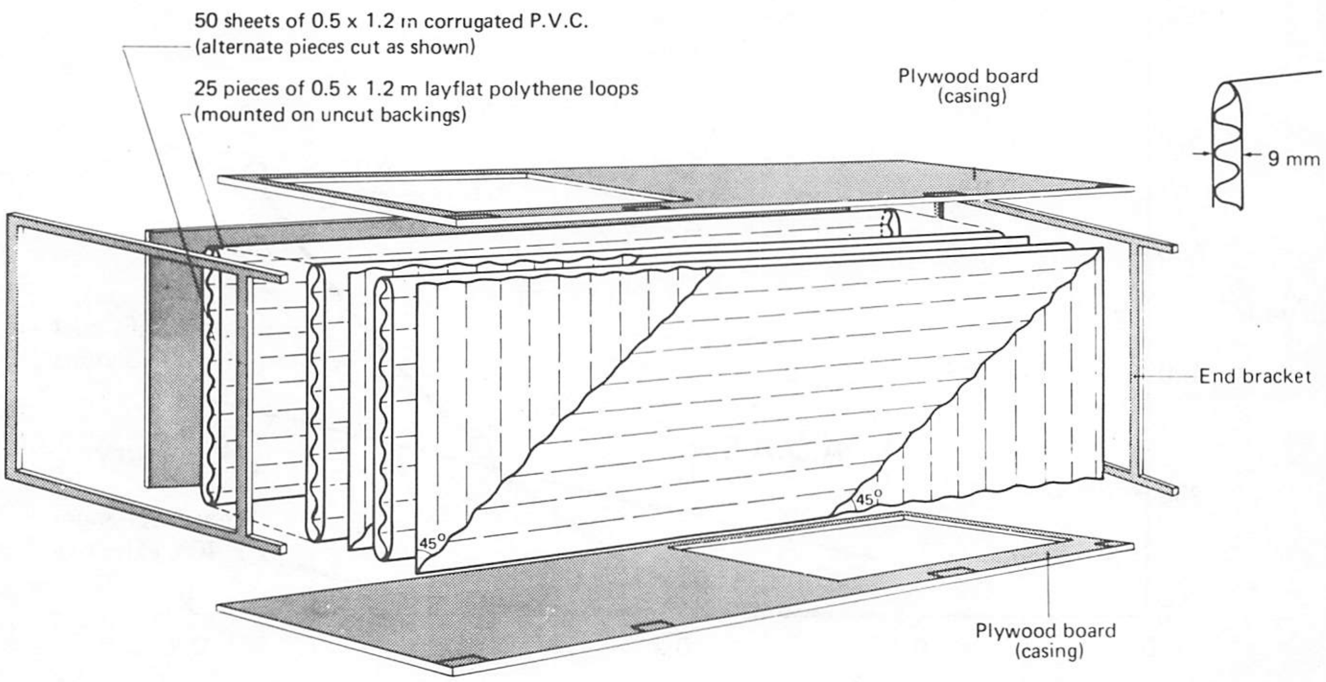
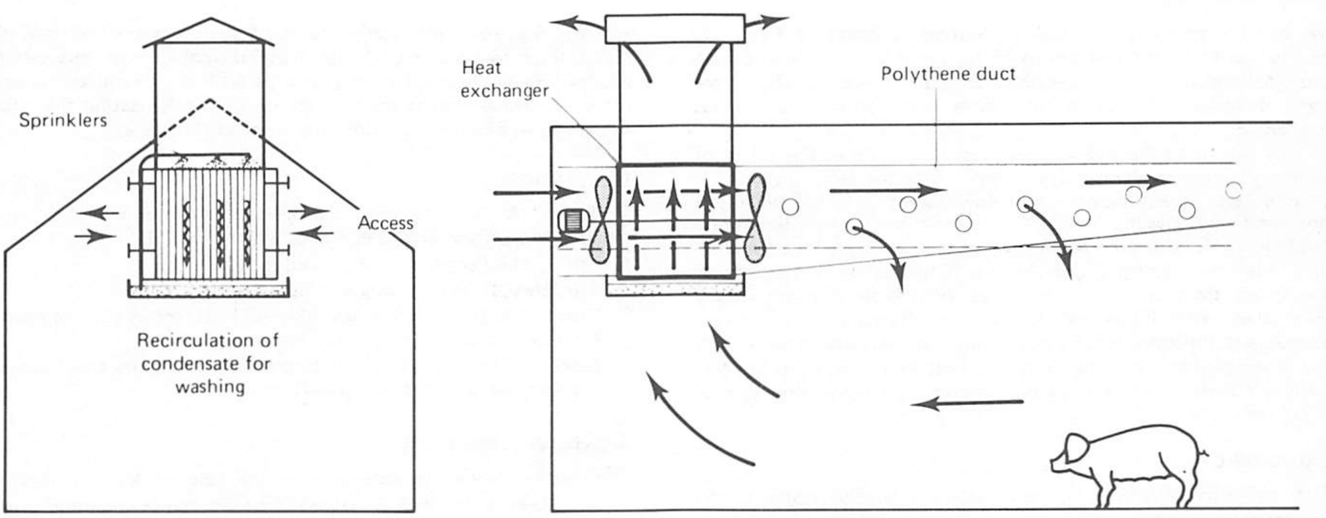


Fig 2 Basic structure of heat exchanger
Fig 3 Overall system



is set by the flow rate required to remove moisture, noxious gases and dust. The inside temperature required is such that the food conversion efficiency and rate of gain are not too adversely affected. Temperature, moisture, noxious gases and dust levels all contribute to animal health and this is a limit to the lowering of ventilation rate which is difficult to quantify.

Table 2 Description of a typical finishing house

Animal data

Number of pigs = 360	Average weight = 62 kg
Heat output/pig = 98 watts,	Moisture output/pig = 112g/h

Dimensions

Length = 30m	Width = 10m
Eaves height = 2m	Ridge height = 3m

Structural heat loss data

Item	Area (m^2)	U-value (watts/m^2°C)	Heat transfer (watts/°C)
Roof	306	0.51	156
Walls	170	1.8	306
Floor	300	0.5	150
	Total surface loss =		612 watts/°C

To assess the feasibility of a heat recovery system, a particular system was simulated using a computer. The finishing house considered is defined in table 2 and has been previously used as an example by Trapp[1]. It should be noted that the size or number of heat exchangers required for this system will depend on the minimum ventilation rate. This is accounted for in the costs and the effectiveness is taken as 40% in all cases.

The computer programme is supplied with the hourly weather data of temperature and humidity for Newcastle upon Tyne over the period of a year. For a given ventilation rate, the internal temperature and humidity for the above finishing house can be calculated at hourly intervals. A heat exchanger of a given effectiveness can also be incorporated into this system and the change in internal conditions observed.

The food consumed by a pig is related to the temperature at which it is kept. Above a certain critical temperature, the pig can adjust without requiring additional food; below this temperature an additional food intake is required which increases in proportion to the number of degrees below the critical temperature. There is also an upper constraint on temperature but this does not affect the heat recovery situation. From the work at the Institute of Animal Physiology at Babraham and that of Bruce[2], a value of 16°C for the critical temperature and an increment of 0.043 kg/day °C seems reasonable for a 62 kg fattening pig kept in commercial conditions. The increment refers to the quantity of additional food consumed

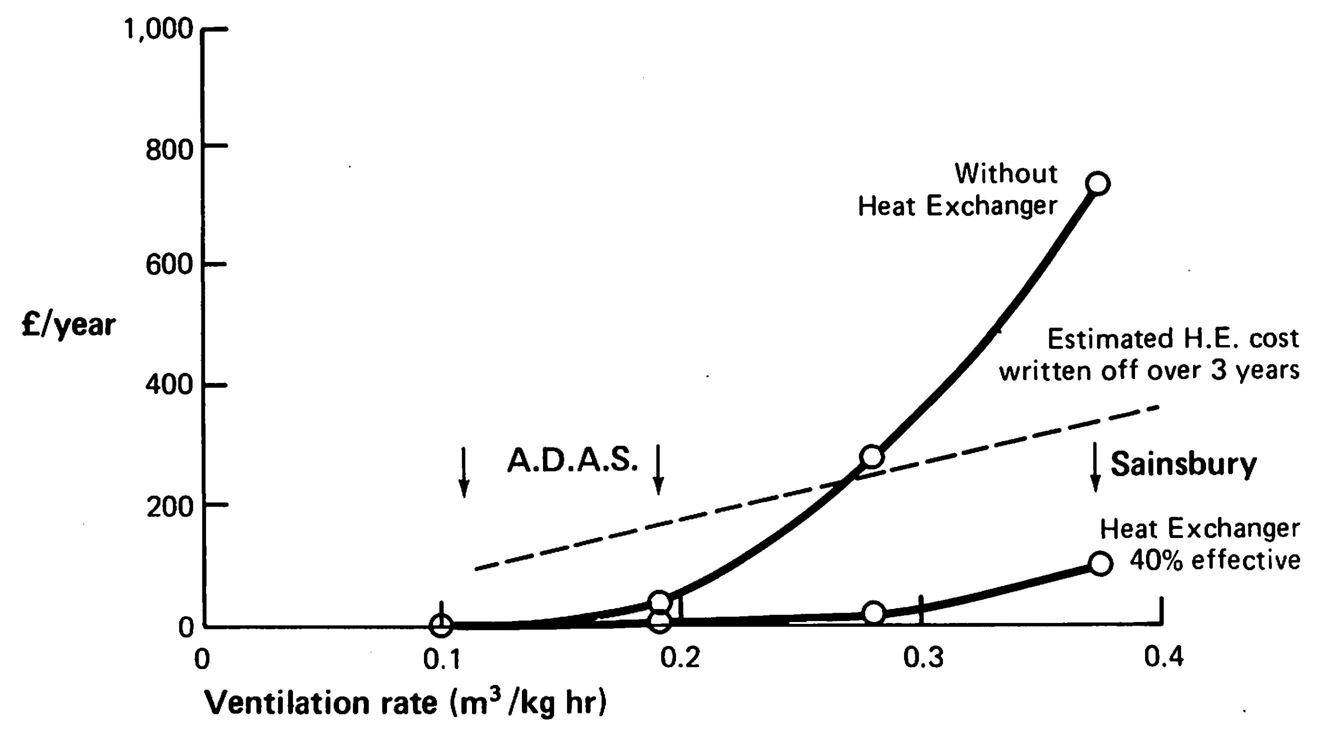


Fig 4 Penalty in food costs over year with and without the heat exchanger.

per day for each degree below the critical temperature. Using the hourly values of internal temperature, the additional food costs* due to temperature can be calculated and totalled for the whole year at various ventilation flow rates, with or without a heat exchanger.

The results of this analysis are presented in fig 4. The effect of ventilation rate on the penalty in food costs due to temperature is pronounced. At ventilation rates below 0.2 m^3/kg hr this penalty is not significant. Recent ADAS recommendations for ventilation rate fall below this. However, at the level of the Sainsbury[3] recommendation the losses are significant. With a 40% effective heat exchanger the losses throughout this range of ventilation rate are largely eliminated. This illustrates that a low effectiveness is entirely adequate in this situation. By comparing the feed cost achieved with the heat exchanger and the estimated heat exchanger costs (3 years write off period), the system breaks even at a ventilation rate of 0.275 m^3/kg hr.

Conclusion

The feasibility of a heat recovery system is largely related to the minimum permissible ventilation rate. The current recommendations suggest that it is possible to operate at levels at which heat recovery is not required. The computer simulation suggests negligible benefit in reducing the ventilation rate below 0.2 m^3/kg hr. However, the criterion limiting the minimum ventilation rate has not been agreed and until the effects of low ventilation rates have been established, the possibility of the need for a heat recovery system remains.

When the work was initiated, the Sainsbury[3] recommendation for minimum ventilation rate (0.375 m^3/kg hr) was widely used. Bruce[4] analysed the feasibility of heat recovery on the basis of this figure and, as the results presented here confirm, the outlook was favourable. Developments in the science and art of ventilation (Owen[5]) suggest that lower ventilation rates are feasible. This would remove the need for heat recovery.

The heat exchanger system described here appears to solve many of the practical problems associated with heat recovery in piggeries. However, the future of heat recovery systems in animal housing in this country is very much dependent on the success of current work on lowering the minimum ventilation rate. The limitations imposed on ventilation by noxious gas levels, pathogens and dust will only be established by commercial experience as these low ventilation rates are introduced more generally. The effect of these factors on the welfare of the stockman and the health and/or productivity of the pigs has not yet been established.

The main features of this type of heat exchanger are its resistance to corrosion, low cost relative to metal plate devices and ease of dismantling for cleaning. These features make it an interesting proposition in the crop drying field as well as in ventilation heat recovery. These results do not appear to justify testing the heat exchanger in a commercial finishing house at this stage.

* *Based on feed cost of £115/tonne.*

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Acknowledgement

The author wishes to acknowledge the help of Mr J T Hayes, Mr L T Maguire and Mr E Z Mahmud who worked as undergraduates on the exchanger as part of their course in the Department of Agricultural Engineering, University of Newcastle-on-Tyne.

Forage conservation in the '80's

A CONFERENCE to be held from 27 to 30 November 1979 at the Bedford Hotel, Brighton, is entitled Forage conservation in the '80s' and is being organised by The British Grassland Society.

The conference is expected to attract many European research workers, advisers and others working on this most important subject. The programme, with both plenary and specialist sessions, will include:—

- Production of forage crops
- Principles of different conservation techniques
- Mechanisation of harvesting and transport
- Methods of forage conservation
- The nutritive value of conserved forages
- Conserved forages in animal feeding systems

The Royal Smithfield Show will be held in London during the week starting Monday 3 December. It is planned to organise a post-conference technical tour of farms and research centres, which will also include a full day's attendance at the Smithfield Show. It is also hoped to arrange a special programme for wives and other associate members who will be attending the conference.

Details from the Secretary, British Grassland Society, Grassland Research Institute, Hurley, nr Maidenhead, Berks.

Reducing field losses in grain harvesting operations

W E Klinner

Summary

FIELD losses in quantity and quality occur for a variety of reasons, some controllable and some not. The paper briefly examines the different types of harvest losses and how they may be assessed and minimised. The mode and timing of harvest operations are probably the most important controllable factors which govern the final total field yield of cereal crops.

1 Introduction

Among the many causes contributing to field losses are the following:

- changing crop characteristics with advancing maturity,
- changing field conditions with advancing season,
- use of inappropriate harvest system:
  - method unsuitable
  - capacity inadequate
- harvest system not optimised:
  - operatives not fully effective
  - equipment not maintained or set to best advantage
  - support services insufficient
- inadequate contingency provisions.

Good preparation and management can reduce the impact of all these aspects, even the first two which are time dependent.

2 Pre-cut losses

For the full potential seed yield to be obtained, cereal crops must have reached at least morphological ripeness before harvesting commences[1]. In temperate climates so-called binder ripeness follows within a few days and combine ripeness traditionally within a further week or so[2]. However, where a grain drier is available, combining can start much earlier, and in hotter climates the interval between morphological and harvest ripeness is sometimes quite short.

On reaching maturity the crop immediately becomes subject to dry matter losses by leaching and oxidation and to shatter losses due to wind, birds and wildlife. The losses increase with time because the effects of exposure are cumulative, and the ease with which seeds and whole heads become detached from the straw is progressive.

Two sets of measurements made at the NIAE, to obtain examples of pre-cut shatter losses for wheat and barley in UK conditions, have given the results shown in fig 1. They were obtained during a normal season of variable weather. Typically the losses consisted largely of free grains in wheat and broken off heads in barley[4]. Because the varieties were fairly resistant to shedding, the acceleration in loss rate was probably less than for some other popular varieties.

Examples of the two main components of pre-cut losses in typical European climatic conditions [3,4] are included in table 1.

Table 1 Losses of potential grain yield before harvesting, %

Loss	Crop	Time from combine ripeness 3weeks	5 weeks
Dry matter	wheat	1.5	2.5
	barley	2.0	5.0
Shatter	wheat	2.0	4.3
	barley	1.7	3.7
Total pre-cut	wheat	3.5	6.8
	barley	3.7	8.7

W E Klinner is head of Forage Machinery Department, NIAE.

Based on a paper presented at the seminar on post-harvest losses organised by the Tropical Products Institute London, 14 March 1978.

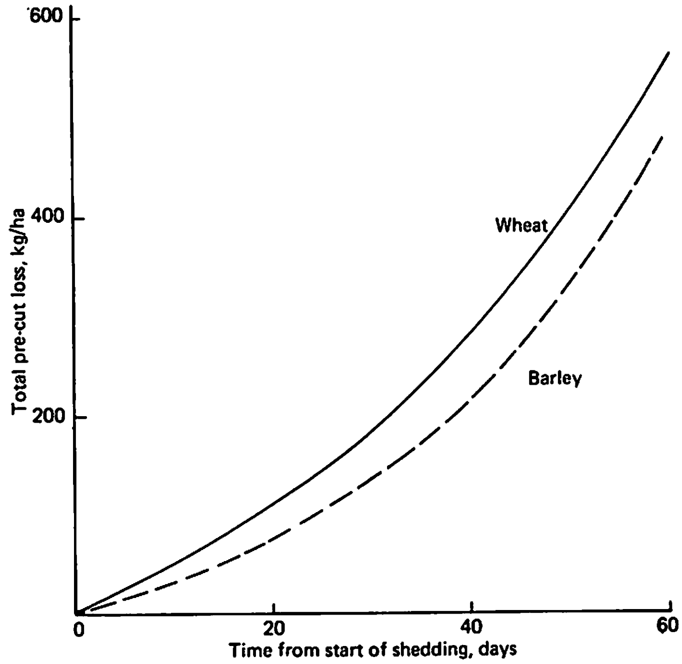


Fig 1 Normal progression of shatter losses in wheat and barley

Better records kept of the characteristic progressions of shatter losses for different species and varieties in the principal growing locations throughout the world could lead to more appropriate staggering of ripening dates through varietal selection and to better planning of harvest schedules. In turn, this could result in appreciable grain savings due to improved timeliness, regardless of harvest method. Plant breeders are making an increasing contribution to the minimisation of shatter losses by the application to this end of genetic engineering.

3 Harvest losses

Some losses are inevitable, whether harvesting is by any of the multi-stage systems based on the sickle, reaper, binder or swather, or by once-over combine-harvesting. Irrespective of the system, the longer harvesting is delayed beyond the earliest suitable date, the more easily and heavily losses are incurred.

3.1 Mechanically induced shatter

Any disturbance of mature crop can dislodge individual grains or whole heads. Disturbance is caused by the movement through the crop of a sickle blade or scythe, and by the action of reciprocating knives and reels of reapers, binders, swathers and combine-harvesters. Further jolting occurs as the crop falls to the ground and is handled during bunching, tying and stooking. Data obtained in wheat in India [5,6] confirm that loss levels depend very much on variety and increase with time of day and date. Typical figures are summarised in table 2.

Table 2 Examples of harvest shatter losses in wheat, % of yield available for harvesting

	Approximate loss
Sickle	2 – 5
Animal drawn reaper	1.5 – 3
Tractor drawn reaper	1.5 – 8.5

Depending on variety, one broken off wheat head per m^2 was found to be equivalent to 14 to 17 kg/ha[6].

Controllable factors affecting harvest shatter include operator skill, the design and sharpness of cutting components, forward speed, and the design, speed and fore-and-aft positions of the reel. As far as combine-harvesters are concerned, most operators tend to set the reel too low and too far forward and drive it unnecessarily fast. American work in the soya bean crop[7] has confirmed the increase of shatter losses with the time of day. A new development to retrieve dislodged beans at the header is the bristle belt recently introduced by a world-wide company. A double tier arrangement of these belts for each row of crop provides two moving canopies which envelope the crop stems, intercept falling soya beans and pods, and feed them into the combine-harvester.

3.2 Cutting losses

Only seed heads above the level of the knife are capable of being harvested mechanically. Figure 2 illustrates the decrease with time in the height of wheat and barley heads above the ground in typical crops in the UK. Since the curves relate to the average distance above ground, a proportion of the heads is at all times appreciably lower than indicated. Similar information for widely grown crops elsewhere in the world would provide valuable guidance for optimising the height setting of cutting mechanisms.

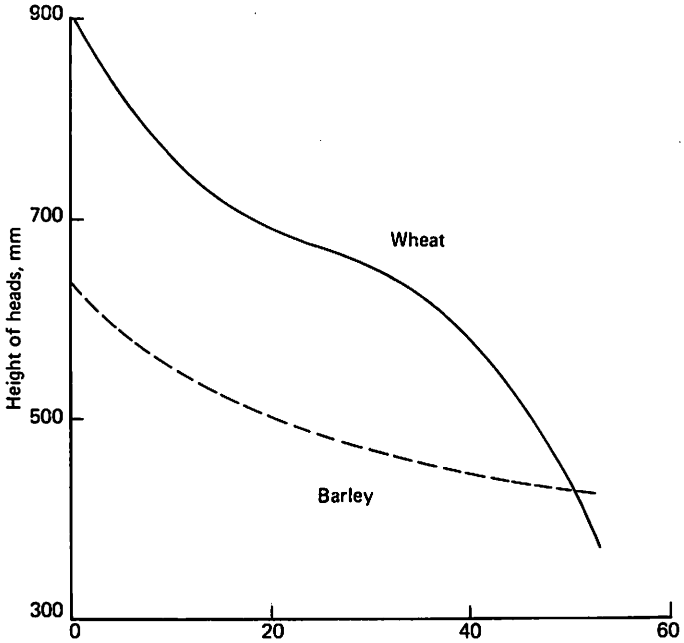


Fig 2 Typical change with time in the height of heads above ground — wheat and barley.

The combined results of crop height and resistance to shatter decreasing with time is illustrated in table 3 by typical data based on European research[3,4] with conventional grain combines.

Table 3 Typical pre-threshing losses, % of yield available for harvesting

Loss	Crop	Time from combine ripeness 3 weeks	5 weeks
Header	wheat	1.5	2.0
	barley	2.4	5.2
Total pre-threshing*	wheat	5.0	8.8
	barley	6.1	13.9

*includes pre-cut losses from table 2

A breakdown of header losses in a crop of UK barley, fig 3, shows that they are mainly in the form of whole or partly cut heads. The same applied to wheat during a sampling period of 5 weeks[4].

In laid crops, cutting losses can be very high, but even a relatively slight amount of crop "lean", as may be caused by the prevailing winds, can have appreciable effects. In these conditions the direction of cutting can make a vast difference to the header losses, fig 4.

Since crops are not normally laid uniformly within fields, a favourable scheme of harvesting can usually be worked out with self-propelled combine-harvester without resorting to one-way cutting. Effective aids to the minimisation of cutting losses in laid

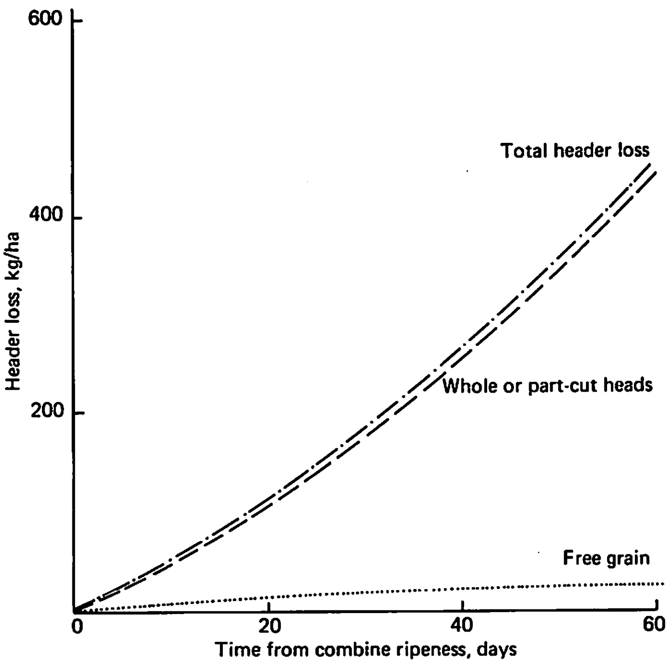
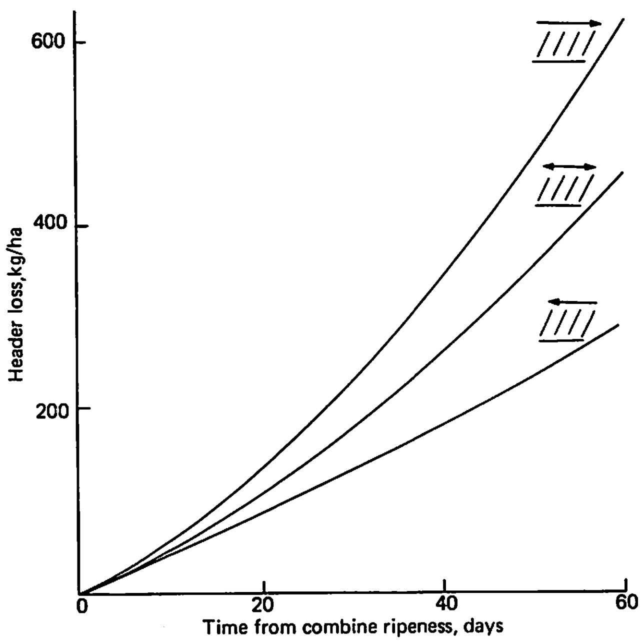


Fig 3 Combine header losses in barley — free grain and whole or partly cut heads (crop lifters fitted).

Fig 4 Combine header losses in barley — effect of direction of cutting (crop lifters fitted).



crops are crop lifters. In one trial in UK barley the use of lifters effected a loss reduction of 4.1% of total grain yield, from 9.5 to 5.4%.

The forward speed of the combine-harvester is a variable which can be used to advantage when other performance considerations permit; at high speeds some crops are often fed more consistently on to the table than at slow speeds, and some of the grain dislodged by reel and knife action may be retrieved.

When close cutting is essential, to recover short or laid crops, the width of the header becomes important. The narrower it is, the better should be its ability to follow ground contours. A UK study in wheat has given the results in table 4.

Table 4 Relative header losses

Header width, m	Rel. header loss, %
4.3	100
2.8	20

With the wider machine, loss levels were particularly high in the region of the crop dividers. This would seem to point towards greater movement vertically and horizontally of the divider assemblies and, hence, to greater disturbance of the crop in the divider zones.

In rice[8] header losses have been found to increase appreciably with cutting height; in one recorded instance the critical cutting table height was 300 mm.

3.3 Threshing and separation losses

Whether threshing is done by stationary machine or combine-harvester, two fundamental rules apply:

1. the more straw is fed into the machine per unit of time, the poorer became grain detachment and separation;
2. the higher the drum speed and the smaller the concave clearance, the more complete will be grain detachment from the crop and separation at the concave, but the higher become the risks of
   (i) grain damage,
   (ii) incomplete separation on sieves and rack — or walkers, and
   (iii) inclusion of impurities in the grain sample.

A simple setting procedure for stationary threshers, to minimise losses, is given in Appendix 2. It is basically applicable also to combine-harvesters, but operators should remember that there is no substitute for the instruction book in the first instance. Fine adjustments to optimise performance depend almost invariably on judgement based on experience.

For combine-harvesters the best compromise between forward speed, cutting height, drum speed and concave clearance must be arrived at in the light of prevailing conditions and acceptable loss levels and sample quality. In fig 5 the relationship is illustrated between grain losses and the straw throughput, which depends on forward speed and height of cut. The relationship is not linear, and sometimes losses increase very rapidly when a critical throughput level is exceeded.

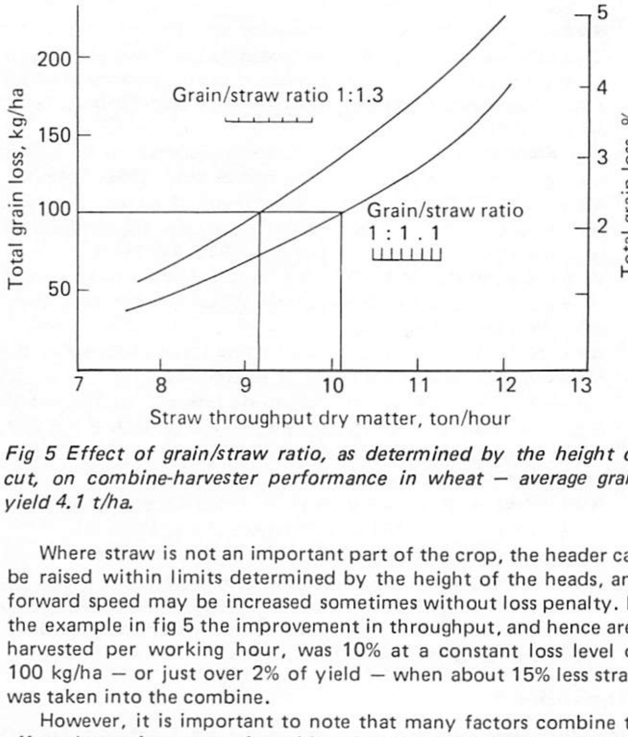


Fig 5 Effect of grain/straw ratio, as determined by the height of cut, on combine-harvester performance in wheat — average grain yield 4.1 t/ha.

Where straw is not an important part of the crop, the header can be raised within limits determined by the height of the heads, and forward speed may be increased sometimes without loss penalty. In the example in fig 5 the improvement in throughput, and hence area harvested per working hour, was 10% at a constant loss level of 100 kg/ha — or just over 2% of yield — when about 15% less straw was taken into the combine.

However, it is important to note that many factors combine to affect the performance of combines from season to season. Figure 6 shows that the performance differences recorded in the same variety of winter wheat in the UK were relatively small during six seasons in a period of eight years. However, during two successive years, five and six, very large differences were recorded, although crop moisture contents were similar at the time of harvesting.

For a typical combine of 3.5 m^2 of separating area, the straw throughput at the same loss level was 82% higher in the best year relative to the worst. Main reason for this was probably the weather during the growing, ripening and harvesting periods which affected the physical characteristics of the crop and hence its response to machine treatment. Crop which has grown very rapidly and is subsequently subjected to severe repeated wetting and drying cycles, tends to become very brittle and hence breaks up easily and quickly during its passage through a harvester. In consequence separation efficiency is low, allowing only low throughput rates; these were the

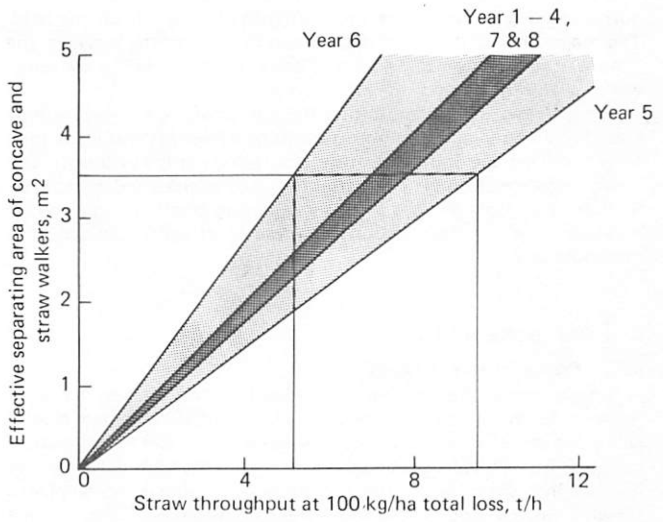


Fig 6 Relationship between combine size, as denoted by the effective straw separating area, and straw throughput at one grain loss level in wheat of the same variety — 8-year period.

conditions which applied in year 5. During year 6 growth progressed very steadily in weather which was moderate in most respects.

More evidence on the effects of straw brittleness, in this instance as determined by the moisture content of the straw, is provided in fig 7.

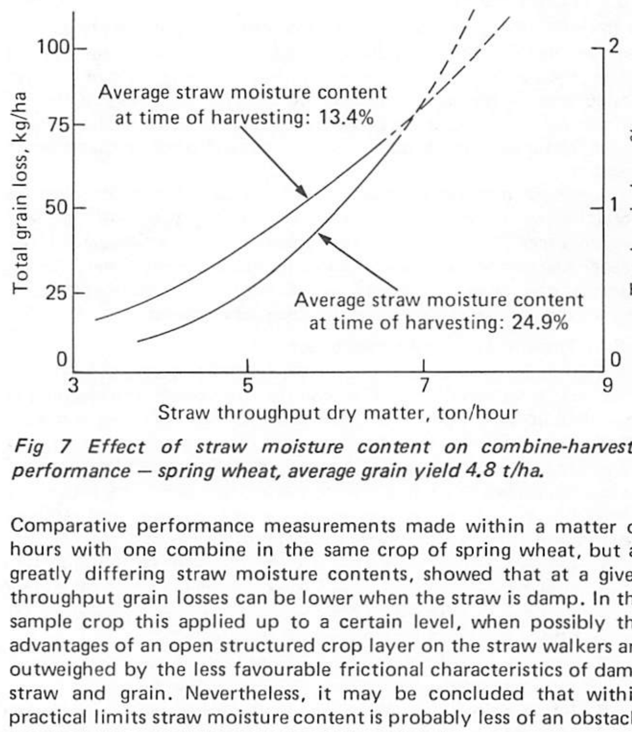


Fig 7 Effect of straw moisture content on combine-harvester performance — spring wheat, average grain yield 4.8 t/ha.

Comparative performance measurements made within a matter of hours with one combine in the same crop of spring wheat, but at greatly differing straw moisture contents, showed that at a given throughput grain losses can be lower when the straw is damp. In the sample crop this applied up to a certain level, when possibly the advantages of an open structured crop layer on the straw walkers are outweighed by the less favourable frictional characteristics of damp straw and grain. Nevertheless, it may be concluded that within practical limits straw moisture content is probably less of an obstacle to successful combining than is widely assumed.

The special problems of rice harvesting, especially paddy, are well known. Data from Japanese studies[8] with different types of combine are summarised in table 5.

Table 5 Comparative combine performance in rice

Type of combine	Average grain loss, %	Average grain damage, %
Conventional	6	3
Head feeding	3	1
Head reaping	1 to 3	0.5

At the time of the studies neither of the alternatives to the conventional combine were found to be entirely suitable for laid crops. Rice variety affected combine performance most, followed by harvest date.

3.4 Transport losses

Untied bundles of crop and sheaves are subject to shatter losses during loading for transport and during the journey from the field. The magnitude of the losses depends on the skill of the workers, the state of maintenance of tools and equipment, including transport vehicles, and the state of the crop and ground.

Body losses can occur during the harvesting operation through cracks and badly sealed joints on combine-harvesters and from grain trailers during the journey to the store. Such crops as linseed and oilseed rape call for particular attention to machines and containers. Spillage of loose grain and from sacks during transloading from the harvester is a common occurrence, yet is so easily avoided with reasonble care.

4 Loss assessment

4.1 Pre-cut shedding losses

A simple procedure for the assessment of pre-harvest losses is referred to in Appendix 1 and fig 9. It entails repeated careful collecting of all shed grains and heads in the uncut crop, using a sampling frame which, preferably, is in two parts; both halves can be lowered into the crop separately without disturbing it and be placed together on the ground into a quadrant or rectangle. To determine the loss per unit area, the collected grains are either weighed and the weight multiplied by the number of sample areas which make up the unit area, or they are counted and the number is multiplied as above and then related to the 1000-grain weight for the particular variety. Because crop yield is never uniform within any field, losses also vary, and this in turn requires that sampling is repeated several times. The total number of samples depends on the field area, the size of the sample frame and the degree of statistical accuracy required.

4.2 Cutting losses

If the sample areas cleared during the assessment of shedding losses can be marked, they may be used again for measuring the cutting losses separately after the reapers or harvesting machines have passed over. Alternatively, counts are taken in the open stubble of all the lost grain, and an allowance is then made for the pre-cut losses. Naturally, the accuracy of this method is lower than that of the first.

A simple method of measuring the header losses of combine-harvesters — Appendix 1 — involves covering previously cleared sample areas with a large cloth-covered frame immediately the header has passed, to keep off all combine efflux. However, the full combine loss measuring procedure — Section 4.3 — provides the best opportunity for pre-cut and header loss measurement.

4.3 Threshing and separating losses

For stationary threshers a loss and grain damage assessing procedure is included in Appendix 2. For combine-harvesters the technique described in Appendix 1 is often sufficient for carrying out spot checks. However, accurate combine loss measurement requires that large samples are analysed[9–11] and, therefore, specially adapted re-threshing and separating equipment is necessary. The procedure which has been adopted in principle by many testing and research organisations can be summarised as follows:

1 the test combine is modified at the rear so that the two streams of straw and sieve efflux can be collected separately on long, usually 50 m, sheets reeled out from separate spools on the test combine during each loss run;
2 loose grain left in the straw on the upper sheet is separated out and constitutes the rack or straw walker losses;
3 loose grain left in the chaff on the lower sheet is separated out and constitutes the sieve losses;
4 grain recovered by re-threshing and then re-sieving the straw plus chaff constitutes the drum or threshing losses;
5 loose grain and broken off heads found on the ground under the sheets constitute the pre-cut shedding plus header losses.

Repeated test runs at different throughput rates provide the data necessary for full performance curves to be established, but it must be remembered that such curves are specific to the test crop and conditions.

A mobile re-thresher developed at the National Institute of Agricultural Engineering, Silsoe, allows the drum, sieve and straw walker losses to be determined simultaneously — fig 8. Its capacity enables a combine-harvester to be evaluated with a high degree of accuracy, if necessary in one hour per crop. Speed is important because changing crop conditions can affect combine performance significantly. A team of four is required for processing the combine efflux, sampling and basic sample analyses. Since its commissioning in 1968 the re-thresher has made important contributions to several research and development projects.

If different threshers or combine-harvesters are to be evaluated in successive seasons, use of a comparison machine of known performance is vital, to enable the prevailing conditions to be assessed in relative terms and to provide a datum for new information. Over a number of years a data bank could thus be built up which is likely to be of value to a number of interest groups.

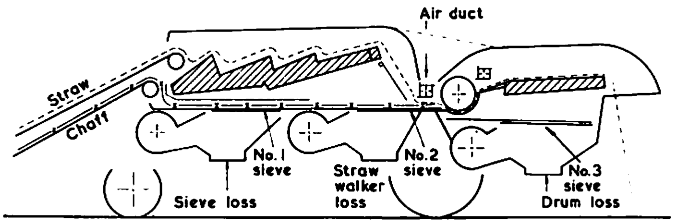


Fig 8 Working principle of NIAE Mk 2 self-propelled re-thresher for combine loss measurement.

Conclusions

Unharvested crop is subject to progressive shedding and deterioration. Harvest losses also increase with time, regardless of the harvesting method used. Therefore, it is economically sound to plan and aim for minimal delay after crop maturity is reached. To this end adequate harvesting capacity and good resource management are vital. They also affect the timeliness of subsequent operations and sometimes even the yield of the following crop. Loss measurement is a good discipline and valuable aid to understanding and influencing the crop/machine interface.

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Appendix 1

Simplified grain loss measuring technique for combine-harvesters

At each site three to six sampling points are chosen, which must be representative of the whole field. The procedure at each point should be as follows:

a. Forward speed is measured by using a stopwatch and measuring wheel, or timing the machine between 2 marked points a known distance apart. Several readings are necessary to check that the speed is constant.
b. Place a wooden peg 2 m from the uncut edge of the crop.
c. As the combine passes the sampling point a tray consisting of a cloth-covered frame is placed on the stubble behind the combine before the efflux from the rear of the machine reaches the ground at this point. The tray should be 1 m long in the direction of combine travel and somewhat wider than the straw swath. On some makes of combine the position of the rear axle makes it difficult to place the tray behind the

rear wheels in time. In these cases the tray can usually be slid under the combine in front of the rear wheels. If the frame is made of suitable wire, it will bend in contact with a wheel but remain useable.

d. Now measure from the wooden peg to the new edge of the uncut crop. 'Actual cutting width' of the combine is this distance minus 2 m.

e. The length of swath on the tray is then separated or cut with shears across its width so that the material on the tray represents the exact 1 m length of the tray.

f. This length of swath is first sorted by hand for unthreshed or incompletely threshed heads. Any such heads are placed in a sample bag for subsequent grain separation and weighing as 'threshing losses'.

g. Any grains remaining on the tray after the careful removal of the straw are retained as separation losses, ie 'straw walker losses' and 'sieve losses' combined.

h. Sieve losses can be measured separately by catching the efflux from the sieves on the tray for, say, 5 seconds and relating this to the width of cut and forward speed,

i. 'Header and shedding' losses combined can be determined using the area of ground which had been shielded from the combine efflux by the tray. A rectangular area, 250 mm long in the direction of combine travel and of width equal to the actual width of cut, is marked out with wooden pegs and string so that it passes through the site formerly covered by the tray. Any grain on the ground within this area is collected and placed in a sample bag marked 'header and shedding losses'.

j. Determination of 'shedding losses' alone entails sampling in the uncut crop with an open wire marking frame in two halves so that it can be lowered into the crop and made up on the ground with minimal disturbance. Alternatively, a marked strip of crop of known area may be cleared of pre-cut losses, which are saved, ahead of the combine – see fig 9. The cleared strip is then covered after the header has passed over, so that the header losses are isolated and may be measured subsequently.

k. All loss samples should be labelled for subsequent cleaning and weighing in grammes. Figures for the various losses can then be calculated in kg per hectare or other unit area.

Appendix 2

Procedure for checking and setting small threshers

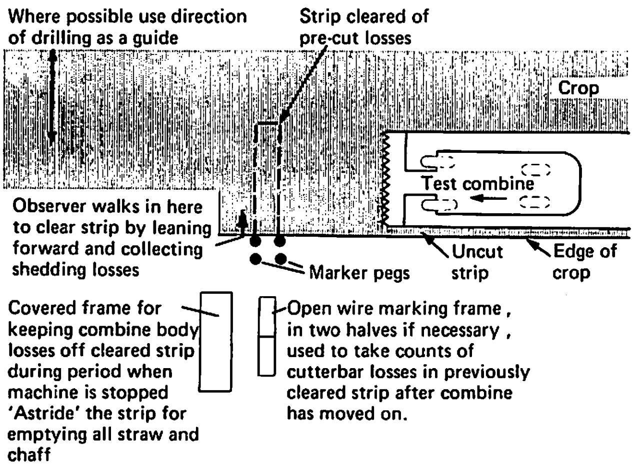
A. *To measure the effects of feed rate and drum speed on losses and grain damage*

1. Start with the peripheral drum speed and concave clearance which are considered to be the most suitable under the prevailing conditions.
2. Feed a known quantity of crop at slow but constant rate into the thresher, measuring the time the machine is loaded.
3. Weigh the quantities of grain, straw and chaff, or grain and straw plus chaff.
4. Separate and measure the loose grain left among the straw and chaff plus the unthreshed grain left in the heads.
5. Determine the visible grain damage by inspecting a 50 g sample (≙ 1000 cereal grains) on a mirror surface and subsequently weighing the damaged grains found; note: if desired the impurities content of the sample can be determined at the same time by also separating the extraneous matter and later weighing it.
6. Repeat steps 2–5, but increase the feed rate within the practical range or until losses become excessive.
7. Repeat steps 2–6, but at one or two alternative drum speeds which could possibly give improved results.

B. *To measure the effect of concave clearance on losses and grain damage*

1. At the optimum combination of feed rate and drum speed repeat steps 3–5 under section A above at concave clearances wider and narrower than the initially used clearance.
2. When the best concave setting is found, it may be used to re-check the effects of drum speed on losses and damage at the higher feed rates (follow procedure in section A).

Fig 9 Procedure for measuring pre-cut and header losses.



Recommendations

The cleared strip should be about 500 mm long in the direction of combine travel and wider than the width of cut of the test combine.

The open wire counting frame must have the exact width of the combine's width of cut and be slightly shorter than the running length of the cleared strip.

The covering frame must be bigger all round than the counting frame.

Farm machinery reliability - A seminar held at Muresk Agricultural College, Western Australia

THE aim of this one day seminar, held in late 1977, was to obtain farmer, dealer and manufacturer reactions to three basic questions. How reliable are agricultural machines? How reliable should they be? What problems do machinery manufacturers face?

In defining the terms durability and reliability for the Conference, the Chairman suggested:

"To durability we can apply a meaning of dependence, and by applying a slight semantic twist we could say that reliability has a meaning of reputation. Therefore reliability is just as important to the manufacturer and dealer as it is to the purchaser. A product sells by its reputation, and in farm machinery, reputations are earned because of reliability."

Another speaker suggested that "farmers express reliability in terms of incidence of failure or breakdown. Their concern is not so much with the inherent quality of the machine, as the amount of time lost from operation-stopping breakdowns and for the repair associated with keeping the machine in operation."

Two components of the durability factor were identified. Firstly fatigue, bending or distortion, and breakage due to weakness. Secondly wear, either normal or excessive.

Despite extensive machine performance testing over a wide range of conditions, advertisements frequently do not include the limitations of the machine or its reduced capacity under certain conditions with the result that on many occasions a machine does not perform as advertised for sale.

Testing and advertising procedures were criticised which provided misleading information about outputs and workrates because of different operating conditions.

The two important aspects of dealer service were:

a) Competent staff. The increasing complexity of farm machinery demands competent mechanics who can properly repair and overhaul machines.
b) Availability of spare parts in the quantity and at the time of need.

All dealers should be supplied with cross-indexed records of standard parts used on the various models of different company machines.

Three important aspects were identified in the farmer's area of responsibility:—

a) Selection of machines suitable for the available tractor power, and from a reputable dealer.
b) The proper operation of the machines in accordance with specifications, and
c) Proper maintenance and repair schedules.

A farmer speaker felt that machinery owners were too eaily fobbed off by seemingly plausible explanations when seeking answers to their problems. Australian dealers had a key role to play. When the dealer did not act on reports he received from the farmer and the manufacturer then it was difficult to establish the necessary lines of communication. Farmers should make the dealer aware of his responsibility and obligations to provide positive help in his role as a go-between.

A metallurgist dealt mainly with failure mechanisms which produce complete fracture and breakdown of equipment. He observed that engineers estimated service loads and designed to stress levels which produced an infinite or useful life. This prediction was invalid where the material was overstressed or contained some flaw induced in manufacture or service. He went on to discuss welding, suggesting that welds which were poorly executed and applied in critical areas generated a large number of failures. The most common mode of weld failure was by fatigue; however, brittle fracture could occur, emanating from hardened zones under the weld. Welds were often applied at points of high stress, and the wrong type of weld was employed. Fillet welds were particularly subject to fatigue failure. This type of weld, and those containing stress concentrators perform poorly in fatigue, yet quite large defects within the body of the weld had little effect on endurance limit.

Emphasis was placed on the importance of using dealer services effectively by having machines serviced and prepared well out of season, not at two or three weeks notice; and obtaining sufficient stock of fast moving parts to be held on the farm so that downtime was kept to a minimum.

The final speaker discussed "Technical Specifications and Cost of Tractors". The first part of the paper covered the relationship between price and technical specifications.

Price response could be related to a fixed unit change in power.

Unit Increase	*Price Change* ($ .000)
50 – 60 kW	1.8
110 – 120 kW	2.4
140 – 150 kW	3.0

This table indicates that a 10 kW increase in power is cheaper in the lower power range.

As a basis for determining trends in power availability on farms, cereal producers in the EEC exhibited a strong association between increases in power availability and cereal output. Australia's variation in cereal output made this more complex, however upward trends in cereal production were expected to produce continuing increases in power availability.

Such trends in power implied increased specialization with tractors orientated to more specific functions. This implied, in turn, increased dependence on reliability.

From a report by Ralph Alcock

Health & safety

THE information series leaflet entitled Agricultural Health and Safety Topics is published by the Health and Safety Executive. Recent topics have included powered components of field machinery, safe transfer of chemicals, dust hazards on farms and safety with pesticides. For further details contact the Executive at Baynards House, telephone 01-229 3456 Ext 172.

The Health and Safety Executive has extended the circumstances for which exemption certificates from the noise requirements of the tractor cabs regulations will be issued. Under the revised procedure exemption certificates may now be issued by the Executive to enable:—

— employers to replace their damaged non-quiet safety cab, frame or roll-bar with a similar model if there is no approved Q-cab available for the tractor concerned; and

— self-employed farmers, who now wish to provide protection for themselves and their families, to fit a non-Q-cab, frame or roll-bar to their pre-September 1970 tractor if there is no approved Q-cab available for the tractor concerned.

A revised list of recommended limits for airborne concentrations of over 500 potentially toxic substances was published by the Executive in August 1978. The limits are under constant review and are revised annually. The latest revision gives notice of Threshold Limit Value (TLV) changes for 51 substances and the main list includes 21 new TLV's which have been adopted for the first time. The publication is entitled Guidance Note EH 15/77 and is available from HHSO.

A discussion document entitled Audiometry in Industry is also available from HMSO. This report of the Health and Safety Executive Working Group on Audiometry invites comments on the value of audiometry in industry and the extent to which this justifies resources compared with other workplace health, safety and welfare activities. Comments should be sent to the Executive by 28 February, 1979.

The Packaging and Labelling of Dangerous Substances Regulations (SI 1978 No. 209) HMSO are being implemented in two stages. Containers with a capacity of 200 litres or more should have been labelled by 1 September, 1978. Containers with a capacity of less than 200 litres must be labelled in accordance with the regulations by 1 March, 1979.

The Safety Representatives and Safety Committees Regulations came into operation on 1 October, 1978. *BAM*

THE Health and Safety Executive, using the facilities of the COI Film Unit has produced a new film on Farm Safety. With the co-operation of HTV this was recently shown to S Wales and Wessex area viewers.

Introduced by John Summerscales NDA AIAgrE, of the Cardiff area Safety Office, it gives a forceful if slightly ingenuous account of some of the more frequent dangerous happenings (the word accident is out!) on farms and illustrates how safety cabs can mitigate the results. Comparisons are drawn between a 1916 Saunderson and a modern MF with cab — a long drawn analogy, but it is good to see the "old-un" again. Typical dangerous practices which are depicted include:—

Careless towing of trailers on sidling ground: resultant overturned tractor;
Trying to pull out a bogged tractor with a high hitch point: resultant overturned tractor;
Standing alongside and staring whilst in gear;
Trying to get on a moving tractor;
Riding on trailers;
Leaving tractor and trailer with brakes not fully on to open a gate;
— all resulting in run-down accidents.

A brief interlude with Dr Iorwith Evans on handling hay bales and on farmers' lung, and a discussion with a farmer who has survived carbon dioxide exposure whilst emptying a forage silo provide a balance of non-mechanical accidents. The material is not new but it is dramatically presented.

Tractor drivers I spoke to afterwards who had seen the film were all impressed and in part horrified. I personally felt that the brief Forestry section, which concentrates on safe working procedure whilst felling and loading is very effective. No casualties are shown so the presentation is less shocking than earlier scenes; but there is a good spoken commentary.

This is a good documentary which should quickly be circulated to all the teaching colleges and around YFC and NFU meetings.

K A L Roberts

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