THE AGRICULTURAL ENGINEER

JOURNAL and Proceedings of the INSTITUTION of AGRICULTURAL ENGINEERS

Volume 36 Spring 1981 No1 (ISSN 0308-5732)

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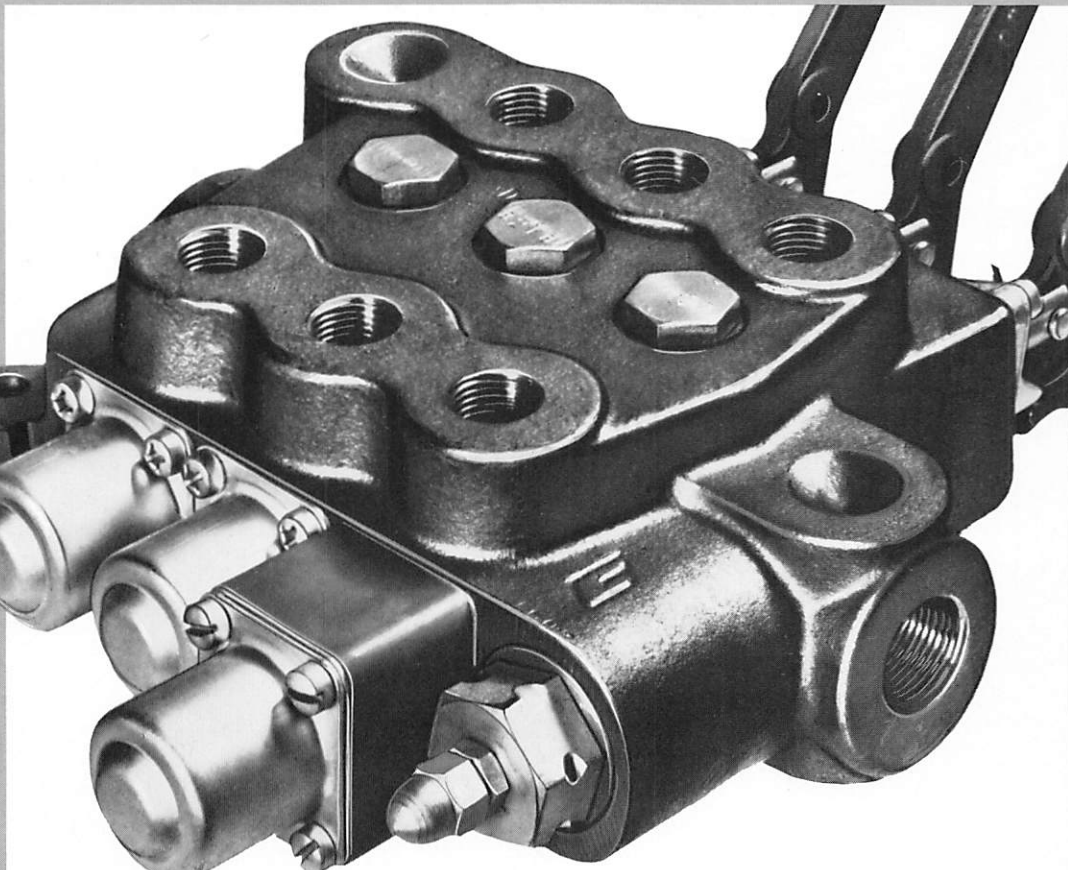

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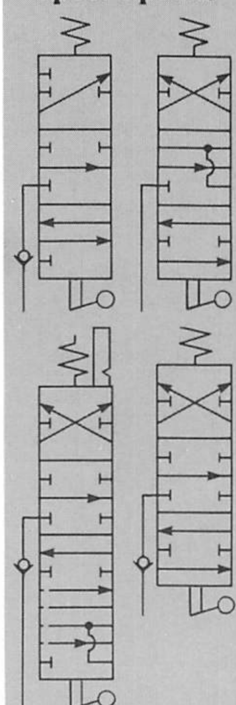

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Editorial changes for the Journal

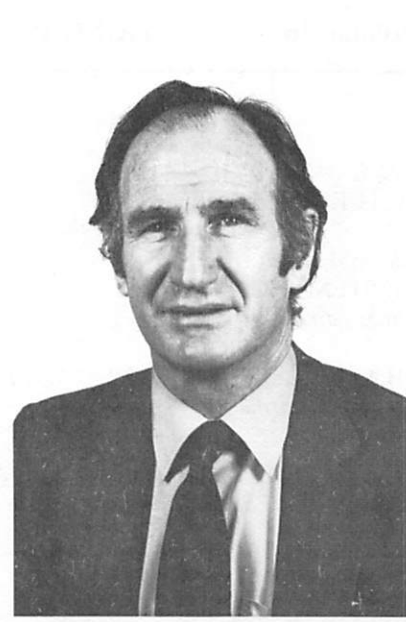
B C Stenning

THE role of the journal of a professional engineering institution, and hence the duty of the editorial panel of such a journal, is primarily to publish scientific and technical papers which are relevant to the interests of the members of the institution. The range of subject matter and the style of presentation must be kept under constant review; the degree of specialisation and the depth of penetration of papers must keep in step with and reflect the aims, ambitions and development of the profession. In order to avoid stagnation of the journal, even if for no other reason, it is therefore necessary for changes to take place from time to time in both the editorship and the membership of the panel.

Since I assumed the Editorial chair, taking over from Professor Brian May in 1976, the Institution of Agricultural Engineers has experienced a number of important changes. Among these one may cite the opening of the new headquarters building which quickly swung into action at Silsoe, the birth of the Institution Newsletter which accepted the responsibility of publishing domestic matters such as membership details, the successful application of the Institution for Affiliate Membership of CEI and, latterly, the formation of the first of the Institution Specialist Groups — the Crop Drying and Storage Group. Each of these changes has been reviewed by the Editorial Panel and has led to some development in the "outlook" of the Journal. Other developments, in order of increasing importance, have included: a "facelifting" change of type face; the initiation of a series of mechanisation articles which aims to review, at intervals, the range of techniques and equipment available for specific agricultural engineering tasks; and the policy of critical refereeing of scientific papers which are submitted for consideration, in order that the Journal may be seen by authors to be on comparable footing with other refereed publications.

The overall aims of the Journal, together with its administration, have remained unaltered. It should be pointed out, though, that the membership of the Editorial Panel now includes two members of Council who are nominated by the President. Currently these are Mr Dick Chambers, Machinery Development Manager of J W Chafer Ltd, and Mr J G (Hamish) Shiach. Mr Shiach, who is Chairman of the Engineering and Farm Buildings Group, in the School of Agriculture, Aberdeen, and Senior Lecturer in the University of Aberdeen, has recently accepted the role of Deputy Honorary Editor of the Journal. After a five year period as Honorary Editor the time is ripe for me to

Brian Stenning



Hamish Shiach

relinquish the post, and Hamish has agreed both to accept responsibility for editing this issue of the Journal and to assume the editorial chair until the Annual General Meeting of the Institution, when the new incumbent can be formally appointed. With his long record (since 1952) in the academic world, being concerned with teaching, advisory and R & D work in agricultural engineering and farm buildings, and having been a full time farmer before this, Hamish Shiach has brought to the Editorial Panel a wealth of wisdom and experience. It is also refreshing to have a viewpoint from the north of Scotland. I very much welcome his recent agreement to deputise as Editor, and, should he be subsequently appointed as Honorary Editor, I would wish him every success.

I would like to record my grateful thanks to the Editorial Panel, the Secretariat, our Production and Advertisement Managers, and the many members of the Institution who have encouraged and supported me during my term of office. In particular, may I mention by name John Neville who, as Deputy Chairman, has been an invaluable provider of practical help and sound advice. It is now time for a new incumbent and I am sure that equal goodwill and support will be extended to him by all concerned.

The Institution of Agricultural Engineers

Annual Conference — 12 May 1981

Innovation in agricultural engineering — its encouragement and utilisation

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West End Road,
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Bridge links for combined cultivation and drilling

D E Patterson and C D Richardson

Summary

THE development and performance of a range of bridge linking devices, which enable more than one cultivation or drilling implement to be operated from the tractor at the same time, are described. Experiments at a number of sites showed savings in labour and costs, with no significant differences in crop yield.

The most satisfactory units were the drawbar type for two pass operation and the pressure link design, both of which are now produced commercially. The one pass system consisting of a chisel plough, rotary cultivator and drill had a rather low work rate and difficulties were experienced with weeds.

Introduction

MECHANICAL linkages[1] permitting the simultaneous use of two or more implements on one tractor, during field operation, have obvious attractions due to greater timeliness, savings in labour and costs, and reduced compaction by wheels.

This paper examines the design and performance[2] of NIAE bridge links for both one pass operation directly into cereal stubble and, for simultaneous cultivation and drilling on land that had already received a primary cultivation.

C D Richardson (NIAE photo)

D E Patterson (NIAE photo)

The one pass link

In 1969 a machine combination was made which was capable of cultivating and drilling directly into cereal stubble in one passage over the ground. It was designed to provide cultivation down to a depth of about 15 cm using a fixed tine cultivator. This implement was chosen because of its low cost, high work rate, compactness and suitability for combining with other implements, and the fact that it does not appreciably smear or compact the soil.

In order to obtain a shallow tilth behind the cultivator and to deal with surface trash the most obvious machine to follow was considered to be a rotary cultivator. Initially a rotary cultivator with a seed drill, was attached using an adapted three point linkage, but subsequent designs were based on a bridge link between the first implement and trailed drill so that a selection of implements could be used in between.

Figure 1 shows the construction of the machine which consists of a set of fixed cultivator tines attached to a main beam having two depth wheels, the frame being supported by an A-frame hitch on the tractor linkage. A second three-point linkage, consisting of two floating links and a top link, passes from the first hitch to the second implement, which allows it to work independently and at a depth different from that of the tines. The tine frame is fitted with top and bottom stops to limit the movement of the second implement and enable it to be lifted at the headland. Depth control is by means of two depth wheels. Implements such as the rotary cultivator and rotary harrow are powered by an extended power take-off shaft from the tractor through a step-up gear box on the tine frame. The bridge link passes from the drill to the turning pivot above the tine frame and then vertically down to a special hitch within the frame, where roll and pitch swivels are located.

The one pass system was used in growing winter wheat successively for four years. The costs, energy and labour requirements (table 1) were lower than those for two and three pass systems based on the plough. Crop yields (table 1) were insignificantly lower. The main difficulties experienced were lack of weed control and problems of blockage at the coulter of the drill when the system was used on cereal stubble or in weedy conditions when the soil was moist. A preliminary operation was therefore necessary to control the level of weed infestation. The other main disadvantage was that the drilling rate was too low because of the other implements in the combination.

Trials in Lincolnshire[3] on heavy clay land intended for winter wheat following

Fig 1 One pass link working on cereal stubble (NIAE photo)

Table 1 Mean energy and labour requirements for separate and combined operations

Cultivation systems	*Soil type*	*No of years*	*Energy MJ/ha*		*Labour man hr/ha*		*Cost* £/ha*	*Yield* tonne/ha*
			First pass	*Other pass(es)*	*First pass*	*Other pass(es)*		
1. *Three pass* Plough, Cultivator, Drill	Clay, Silty Loam	6 6	245 118	75 62	2.6 1.6	1.4 1.0	26.5 16.3	6.44 5.14
2. *Two pass* Plough, Combined cultivator and drill	Clay, Silty Loam	6 6	245 118	79 60	2.6 1.6	0.8 0.7	24.3 15.7	6.33 4.97
3. *One pass* Combined chisel plough, rotary cultivator and drill	Clay, Silty Loam	4 4	185 133	– –	1.7 1.3	– –	16.5 17.6	6.14 4.88

* *The values for cost and yield are based on four years of results*

Brussells sprouts, showed no differences in crop yield; the labour requirement was reduced to about 40% compared with the ploughing system used in this region (table 2).

The adverse soil conditions, which frequently prevail following the sprouts crop during mid-winter, affected the performance of the one-pass system on this heavy soil in Lincolnshire. Even using a four-wheel drive tractor the wheel slip was excessive, the drilling rate was too slow, and there was evidence of smearing from the rotary cultivator.

Table 2 Labour required and crop yields

Cultivation	*Labour requirement, man hr/ha*	*Crop yield, tonnes/ha*
1. *Traditional system* Plough, Disc harrow, Drill, Disc harrow	4.9	4.9
2. *One-pass system* Chisel plough/rotary cultivator/drill	2.1	5.1

Two pass links

Because of the restrictions on use of the one-pass system, other links were designed primarily for operation on ground that had already been cultivated. All units allow for separation for more passes if required.

Two types of drawbar link were constructed for cereals, the first was based on a light "space frame" construction (fig 2) and the other, whilst being a little heavier, was more elegant in design (fig 3 and 4) being manufactured from rectangular hollow section steel. Both are similar in design to the one pass system except that the attachment point is at the drawbar and the bridge can accept both power take-off driven and draught implements. The height on the bridge is such that implements can be raised and lowered on the tractor linkage with sufficient clearance to allow easy turning at the headlands. A feature of both links is that roll and pitch swivels are located at the drawbar which ensures stability even on sloping land.

A third unit, a three point linkage bridge, was constructed (fig 5 and 6) and this is similar to the first space frame link except that the bridge attachment point is within the tractor three point linkage. An "A" frame hitch was adapted by fitting depth wheels whilst roll and pitch swivel joints were fitted at the base to reduce instability. Whilst this outfit is not so stable on slopes as previous types it is lighter and more compact because the bridge lifts with the implement and thus requires only a small clearance distance.

The two pass systems were used successfully in cereal cultivation

Fig 4 Two member link showing connection point to tractor drawbar

Fig 2 Space frame link connected to drawbar

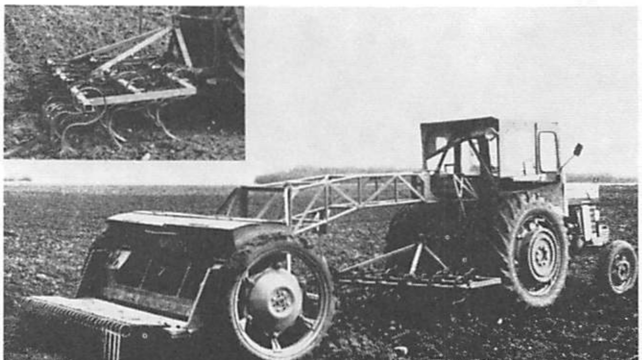

Fig 3 Two member link made of RHS steel

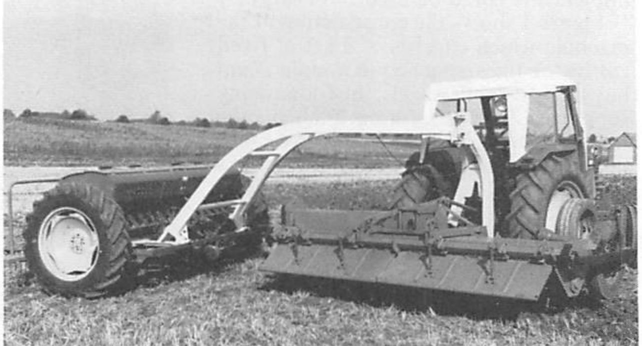

Fig 5 Space frame link in work

Fig 6 Space frame link connected to tractor 3-point linkage

experiments for six years. The four year mean values have been quoted in Table 1 for comparison with the three pass system and these show improvements in costs, a similar level of energy requirements and a large reduction in labour requirements. At the winter wheat sites the combined implements have functioned satisfactorily over a wide range of conditions but on the heavy soil where spring barley was grown, some difficulties were experienced with coulter blockages in wet springs. Under these conditions it was necessary to cultivate the soil in a separate pass to assist drying and hence the following drilling operation.

The drawbar bridge constructed of rectangular hollow section was adapted for sugar beet by fitting two depth wheels and a three-point linkage for the spacing drill (fig 7); the tractor external hydraulics is used for raising and lowering the drill. As in previous designs different secondary cultivation implements can be used with the combination.

In 1975-76 the link was used on heavy land[4] for sowing sugar beet after spring barley but difficulties were encountered. Moist soil, which was exposed immediately in front of the drill, picked up on the press wheels so that they stopped turning and the "bulldozed" soil interfered with seed placement. A further problem was that the drill did not follow the tractor correctly and inter-row spacing varied considerably. The low population of beet and poorer yield (Table 3) following combined secondary cultivation was almost certainly due to moist soil affecting seed coverage and germination.

Table 3 Yield of sugar beet

	Treatment	*Total No of beet*	*Yield tonnes/ ha*
1	Plough, cultivator, spring tine cultivator, harrow, drill	457	31.5
2	Plough, cultivator, rotary harrow/ drill*	335	27.1
3	Rotary digger, harrow (2), drill	490	33.5
4	Rotary digger, rotary harrow/ drill*	385	31.0

** represents bridge link*

Pressure link

Previous designs have been suitable for both power take-off driven and draught cultivation implements. Work rates are generally lower when using powered rather than draught tools with the drill. Thus in 1978 it was decided to examine the merits of a design constructed for draught implements only but with a further advantage of providing a high penetration force on the cultivation implement so that the bridge could be used directly onto cereal stubble as well as on already cultivated ground.

The link made of welded rectangular hollow section steel, (figs 8 and 9) is bolted to the seed drill and connected to the tractor by a drawbar which pivots at the lower point of the frame. A double acting ram is fitted from the centre of the drawbar to the top of the frame to allow raising and lowering of the implement and to provide the necessary loading for the direct drilling application. The unit, which is provided with rubber suspension units to enable the implement to follow ground undulations, can support different implements such as a disc harrow or spring tine cultivator, according to soil conditions. Two links connect the front of the cultivation implement to the frame so that the implement is held in position and cannot move sideways. An easy hitch coupling system is fitted between the bridge and the drill, so that the wider drills can be quickly disconnected and transported separately along the road. The bridge with implement suspended beneath can also be transported easily, the procedure being to replace the drawbar by a tractor three point linkage. Connecting the implement to the bridge is achieved by arching the bridge and driving over the implement at a sharp angle.

In a preliminary trial drilling winter wheat into hard, dry, Oxford clay soil on bean or cereal stubble, the discs penetrated well creating a shallow depth of tilth which was better than the farmer could achieve with two passes of his disc harrow and drilling with a cultivator drill. The overall work rate was nearly two hectares per hour.

Later the performance of the equipment was compared with that of traditional cultivations on heavy land growing winter wheat. The autumn was very dry and this led to poor germination from the ploughed plot compared with the use of the link fitted with a disc harrow and drill directly onto cereal stubble. Final crop yield was about 50% higher from the shallow cultivation treatment as compared with traditional cultivations and work rates were higher.

Experience of using the link in plot experiments and on farms has shown that a disc harrow should be fitted in the harder stubble conditions, both sets of discs should be less angled to provide less wear on the discs. When conditions are sticky, the aim should be to maintain a high forward speed, preferably greater than 8 km/h to reduce soil sticking to the

Fig 7 Link for sugar beet

Fig 8 Pressure link fitted with discs in working position

Fig 9 Pressure link arched out of work

discs. If soil conditions are too sticky then a spring tine cultivator will provide a better quality of work although the tines will not clear satisfactorily if too much trash is present on the surface.

Some farmers have obtained good results when using rollers and disc harrows under the link for working in the spring on already cultivated soil. The object in this situation was to firm the soil to provide a firm seed bed for placement of the seed.

Conclusions

a) The major advantages of combined cultivation and drilling are large savings in labour requirements and a reduction in tractor wheelings.

b) The one pass bridge link is not a suitable system for continuous cereals but may have application for growing winter wheat on the drier soils following a vegetable crop where weed control is not so difficult.

c) The drawbar bridge is in commercial production. It is more stable on slopes than the three point linkage version and it has application on a wide range of soils because it can be fitted with different secondary cultivation implements including draught and pto driven equipment.

d) The adapted link for sugar beet has not proved successful and it will be necessary to consider other designs such as use of the tractor front mounted linkage for the secondary cultivation implement with the drill close-coupled to the tractor to avoid the difficulty of poor following of the drill. Combined cultivation and drilling for sugar beet is likely to have application on the medium and lighter soils.

e) The pressure link for cereals which is now being manufactured commercially provides a high degree of penetration by weight transfer and a greater degree of surface soil tilth than conventional direct drills. It should have wide application for direct drilling as well as traditional and reduced cultivations.

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Books

Irrigation, Design and Practice

THIS book, which first appeared in 1974, published by Batsford (London), has run to two editions in Britain and in 1980 was taken up by the present New York publishers. Written primarily for students of agricultural engineering and for civil engineers who may be moving into the field of irrigation, the book combines the two different disciplines of soil science and hydraulics. Sociological and management considerations are not ignored, and in its technical coverage the book sets out, in a clearly understandable way, both the analytical and practical aspects of irrigation.

Irrigation — Design and Practice, by B Withers and S Vipond, published by Batsford (London), 1980, Cornell Univ. Press (New York) 1980. BCS

Forage conservation in the 80's

This four day conference gave rise to 73 papers on a very wide range of aspects of forage harvesting, postharvest treatment and animal nutrition. Authors of international reputation placed emphasis firmly on the anticipated developments in Europe for the present decade.

Introductory papers in the edited proceedings review the structural and economic situation within which conserved forage will be produced. These are followed by numerous papers giving the results of recent research. Finally, there are brief reports of the deliberations of specialist discussion groups which met to consider research methods.

A thorough review of such a publication is not a realistic proposition; suffice it to say that the book will be an invaluable addition to the library of any worker in the field of forage harvesting, conservation, handling or feeding, whether he be concerned with research, machinery design, implement selection, crop storage or animal production.

Thomas C (Ed), Forage Conservation in the 80's: Proceedings of the European Grassland Federation Conference 27-30 November 1979. Published by the British Grassland Society £14, inc p & p. BCS

Drying and storing combinable crops

THE importance of grain and other "combinable" seeds, both economically and nutritionally, cannot be questioned. The successful postharvest treatment of these products on the farm is vital, but it is no secret that there exist many drying installations which suffer from unsatisfactory design or inadequate supervision on the part of the operator.

This book sets out clearly, in good practical terms, the means by which success in drying, handling and storage of seed crops on the farm can confidently be achieved. Principles of drying are covered with sufficient thoroughness for the reader to appreciate the lucid description and explanation of techniques which are used in farming practice.

A fairly standard approach is taken to the important matters of grain moisture measurement, fans and fan characteristics. This then leads to a particularly informative section on the low temperature drying of grain in bulk. The need for a thorough understanding of this process by the user is strongly emphasised and a guide to the diagnosis of problems, based upon simple measurement and observation, is a valuable inclusion. Occasional calculations of such factors as airflow rate, static pressure or duct size keep the reader on his toes and serve to illustrate important features of design.

High temperature drying techniques and alternatives to drying are reviewed, low volume ventilation being comprehensively treated.

It is appropriate, in this very practical book, that the matter of safety should receive significant attention. Potential hazards are mentioned at intervals through the text and the general problem of safety in stores is the subject of the entire final chapter.

It is a pleasure to review a book, by an author of the experience of Mr McLean, which so well fills an obvious gap in the farming library. The volume is warmly recommended to the attention of owners and operators of grain drying units and to students who are concerned with this aspect of agriculture.

Drying and Storing Combinable Crops., by K A McLean, Farming Press 1980, £8.25 from booksellers; £9.00 by post from the publisher. BCS

Prediction of the dynamic performance of tractor - implement combinations

D A Crolla

Summary

SIMULATION is shown to be a powerful computational technique for many of the engineering dynamics problems which occur in agricultural machinery.

The specific example of the field performance of a tractor-implement combination is discussed to illustrate how simulation was used as an aid to understanding system behaviour and as an engineering design/development tool.

Introduction

OPTIMISING the field performance of tractor and implement combinations has occupied the efforts of many research workers virtually since the introduction of the tractor. These predictions have improved as

(a) mathematical techniques have improved and
(b) more empirical data have been measured.

We must, however, start by making a clear distinction between the two approaches to the problem, namely:

(a) steady state
(b) dynamic

A steady state analysis assumes that for a particular operating condition all the parameters, eg draught, slip, etc. are non-varying. Dynamic analysis attempts to represent the practical conditions more accurately by including the dynamic effects of the continuously varying parameters.

Steady state analyses have attracted more attention, perhaps because they are simpler and because predicted work rates can be calculated fairly quickly. A recent paper by Gee-Clough *et al*[1] reflects the current state of the art of the steady state prediction of tractor and plough field performance. Empirical relationships for tyre tractive performance and plough draught force were used and then, by equating pull delivered to pull required, an analytical expression was derived. The solution defined a steady state operating point and it was subsequently not a difficult task to write a computer programme to solve this expression for a range of parameter values and search for an optimum within the range of operating conditions.

Progress on the dynamic analysis of tractor and implement combinations has virtually all taken place at NIAE, Silsoe, Bedfordshire. The work was initiated in order to study tractor draught control performance specifically[2], but as this research developed, it became apparent that the scope could be extended considerably to look at overall tractor and implement field performance. Digital simulation was one of the techniques which was successfully employed in this work.

The objects therefore of the paper are:

(a) to introduce the techniques of digital simulation and briefly describe its applications in agricultural engineering,
(b) to show how this technique has been used to analyse the problem of the dynamic performance of tractor and implement combinations.

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Simulation systems

The objects of simulating an engineering system are to predict and understand its behaviour. Three separate stages are involved in this process.

Mathematical modelling	The real system is modelled by describing it in terms of mathematical equations. The assumptions used at this stage are crucial to the accuracy of the model.
Computation	The equations are solved. Standard computer methods will almost certainly be used.
Verification	The degree of confidence placed in the model depends on the extent to which its predictions have been verified by comparisons with experimental results. In some engineering applications this stage may not be feasible (eg spacecraft) but this restriction will not usually apply to agricultural engineering.

It is in the computation stage that most advances have been made over recent years. Analogue computing has to a large extent been superseded by special simulation languages written for digital computers. There are many examples of these (CSMP, SLAM, SIM-11, CSL, DYNAMO, etc) but they all contain integration routines and they are all aimed at allowing the user to simulate a continuous system. Normally, the independent variable will be time, and the programme operates by calculating all system variables at small increments of time. Thus, it enables the user to monitor the performance of an engineering system as time proceeds. For our particular example, therefore, it is becoming apparent that we will have the facility to monitor continuously the performance of a tractor and implement over, say, one traversal of a field.

The advantages of digital simulation are as follows.

i) Other than computer space, there is little restriction to the complexity of the model.
ii) Non-linearities are easily simulated. Experience has shown that this advantage is particularly relevant to agricultural engineering problems. The only potential danger is that of trying to integrate discontinuous functions.
iii) Simulation programmes are typically easy to use and a specific problem can often be solved relatively quickly providing accurate input data are available.

The disadvantages of simulation programmes are:

i) They can be expensive on computer time although advances in computer technology are making this aspect less important.
ii) Because they are easy to use there is a tendency for the engineer to assume that they can do the "thinking" for him. In this case he will end up with, at best, little understanding of the results or, at worst, incorrect results.

However, provided they are treated

with an appropriate understanding of their limitations, there is no doubt that digital simulation languages are a powerful computational tool. It is interesting below, to note some of the agricultural engineering problems which have been investigated using this technique.

i) Power take-off drivelines — torsional oscillations[3] starting up behaviour of pto machinery and tractor drivelines[4].
ii) Tractor and tractor/trailer ride dynamics[5]
iii) Off-road vehicle handling, steering and braking[6]
iv) Tractor automatic control systems[7].

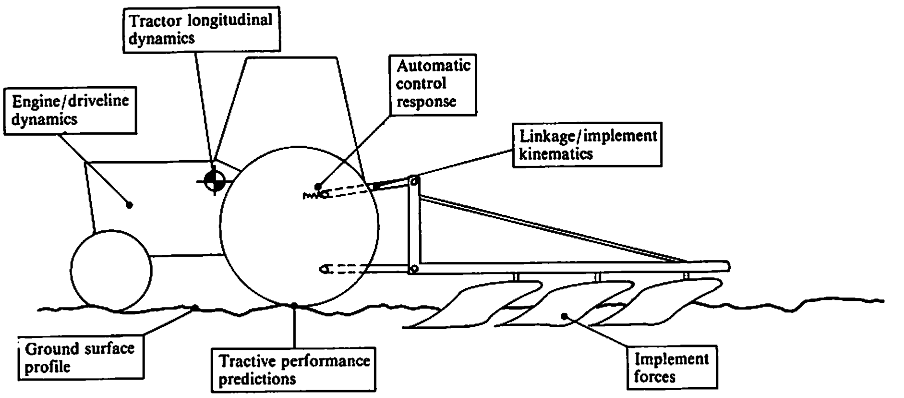


Fig 1 The important features of a tractor-implement model

Tractor/implement model

Figure 1 is a diagram of the tractor and implement operating on a typical undulating surface. The important areas governing the performance of this engineering system are marked in boxes. In the modelling process we represent the physical relationships in each of these areas by mathematical equations. And when the equations are then linked together we have a model of the entire system.

The important assumptions used in this model are:

i) It is two dimensional and has therefore freedom to move in the longitudinal, vertical and pitch directions only.
ii) The wheels are assumed to follow the ground contour exactly and since tyre stiffness is ignored, ride vibration motion of the tractor is ignored.
iii) The soil is homogeneous.

Details of the equations are contained in Ref 7 and need not be repeated here.

However, it is worthwhile briefly mentioning several general points relating to the derivation of the equations.

Engine/driveline dynamics

By referring all the inertias contained in the drivetrain to one point, say the engine flywheel, an equation of the following form results

Referred inertia x engine acceleration
=Σ Applied torques (1)

Note that driveline stiffnesses are ignored on the basis that they will only influence behaviour at frequencies higher than those of the overall tractor motion.

Tractor longitudinal dynamics

The governing equation is of a similar form to that above,

Total mass x acceleration
= Σ Applied forces (2)

where the applied forces are due to tractive effort, rolling resistance and plough draught.

Note that from equations (1) and (2) and the geometrical restraints, wheelslip can be calculated.

Automatic control response

In detail, this becomes rather complicated and is a research study in itself. However, the various non-linear features, eg deadband, delay time and saturation of the hydraulic control can be incorporated easily in the simulation programme. Conventional top link sensing control depends upon firstly calculating the top link force. However, this in turn merely depends on knowing the linkage geometry and implement forces.

Linkage/implement kinematics

In side view, the linkage is simply a version of the classic four bar linkage and as such its motion can be described mathematically. Hence, the motion of the implement following either a tractor or linkage displacement (or combination of both) can be described. A particular non-linear feature of tractor linkages is that they are constrained only in the lowering direction and are free to 'float' upwards.

Implement forces

In general, the forces on the implement for a particular soil condition have a non-linear relationship with depth. They must therefore be read into the programme as empirical curves of draught and vertical force v depth..

Tractive performance predictions

The tractive performance of agricultural tyres has been studied extensively. For a given tyre, inflation pressure, soil and surface condition, tractive effort is a non-linear function of wheelslip and vertical load[8]. In order to simulate this we can either read in the data appropriate to a particular case or alternatively use one of the empirical relationships already derived[1].

Ground surface profile

The ground coordinate points for a typical surface profile are read into the programme as input data. In order to simulate a surface which is relatively rougher or smoother, these coordinate points are scaled up or down respectively. The mathematical justification for this is based on the slope of the ground surface power spectra curve[7].

Having outlined the mathematical modelling process, (the most demanding part in terms of the engineer's skills), brief mention of the computation and verification stages must be made. The computation was carried out using CSMP (Continuous System Modelling Program), a simulation language written by IBM. Output can be extracted from simulation runs in virtually any form that the user wishes. As an example which was specific to this problem, an additional FORTRAN sub-routine was written to analyse the draught force fluctuations during each run (ie the length of the typical field). Thus, an amplitude distribution was produced to illustrate, at a glance, the draught control performance. The full computer programme is available from NIAE[9].

The verification stage was based on two series of fieldwork in which a tractor and implement was subjected to

(a) a repeatable sinusoidal disturbing input obtained by mounting the tractor rear wheels eccentrically[10].
(b) random fluctuations arising from naturally occurring field surfaces[11].

Typical parameters varied during these experiments were:

i) implement — mouldboard plough, chisel plough
ii) control — top link, lower link, pure draught, linkage position, driveline torque sensing[12]
iii) linkage — fully or semi-mounted
iv) forward speed — 1.0 to 2.8 m/s
v) control parameters — deadband, rate of lift/lowering
vi) field conditions — 16 fields in total.

Considerable model development took place in parallel with the field measurements and the satisfactory agreement reached between predicted and experimental results have been reported in detail previously [10-12].

Simulation as an aid to understanding

There are many ways in which results may be obtained from the tractor/implement simulation, but firstly we must understand why dynamic performance is important and why it is different from steady state performance.

Figure 2 is a graph which attempts to explain why only a fraction of the tractor engine power appears as useful tractive power. Power is plotted against coefficient of traction. It will be recalled that, Coefficient of traction

$$= \frac{\text{Pull produced by tractor}}{\text{weight on driving wheels}}$$

For a given weight on the tractor driving wheels, the x axis is therefore directly proportional to the pull produced by the tractor. The results outlined in figure 2 are based on a conventional two-wheel drive tractor and three furrow plough.

Starting with the top line which shows the engine power available, we must subtract losses due to:

i) driveline friction, viscous drag, etc
ii) rolling resistance of tyres
iii) wheel slip.

The curve then obtained is the maximum tractive power available assuming steady state conditions. The curve is smooth because an infinitely variable gear ratio is assumed so that the engine can always be operated at maximum power. If the constraint of a finite number of gear ratios is added, then the picture is one of a series of curves which touch the maximum power curve at one point only (ie peak power in a particular gear).

In practice, of course, we cannot achieve these idealised steady state conditions where the draught, pull and slip etc. are non varying. Nor can we achieve the predicted power output (steady state). The actual power output under dynamic conditions is shown by the curve below the steady state curve and the discrepancy is accounted for by the 'dynamic losses'.

We can now examine why fluctuations in draught and hence wheelslip, forward speed pull etc. should result in an overall net power loss. To do this, we must analyse the possible sequences of events following an increase in draught force, but because we are dealing with a complex dynamic system it is not possible to predict exactly what happens — hence the need for a simulation model. In an extremely simplified manner though, fig 3 illustrates the behaviour. There are two main routes by which power is 'lost'. In the left hand route the engine speed moves away from its maximum power peak.

Notice that this loss will not be made up during the periods when engine speed is too high, because power will merely be 'lost' by operating at the other side of the peak. In the right hand route, wheelslip increases and therefore, tractor forward speed decreases. Again, this loss is not made up during periods when the wheelslip is lower than average, because the pull v. slip curve is not linear. In fact, it always has the increasing slope characteristic illustrated at the bottom of fig 2. Therefore, the 'losses' due to a given percentage pull increase are always more than the 'gains' due to pull decreases.

It should now be clear that if we require a more detailed insight into this behaviour, then we can run the simulation programme, plot out a time-history of the important variables and examine the precise sequence of events. This is an example of how the simulation

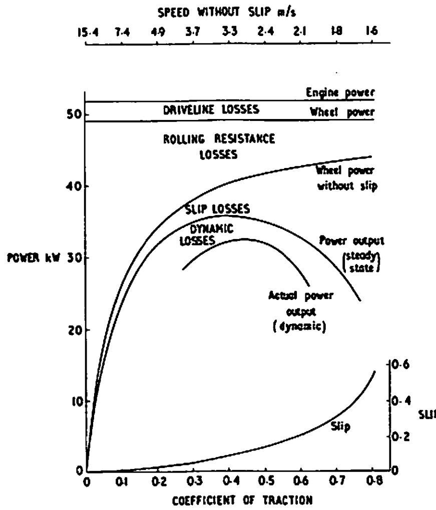


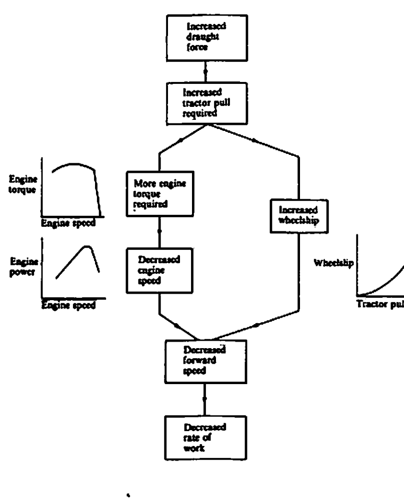
Fig 2 Tractor power output v coefficient of traction, tracing the losses which occur between engine power and useful tractive power available.

programme has already been used to improve our understanding of the tractor/implement system. Without the programme, for example, it is impossible to predict analytically which route (fig 3) will occur for a given set of conditions.

If we compare the dynamic and the steady state curve in fig 2, it is noticeable that the difference between them, ie the dynamic loss, is greatest towards the ends of the dynamic curve. In these regions, the tractor would be working at either a higher speed or higher coefficient of traction than normal. It is not surprising to find that any deficiencies in the draught control system have a more marked effect outside the normal range of operation, eg where the slope of the slip v pull curve is greater.

The best practical method of quantifying the dynamic losses is in terms of tractor work rate. Taking a typical medium power tractor and three furrow plough, the simulation predicts from an eight percent decrease on a good field surface to a 14% decrease on a slippery field surface, compared with the predicted steady state figures. Field data gathered during draught control research work bear out there predictions.

Fig 3 A simplistic view of the possible sequence of events following an increase in draught force — including three diagrams illustrating the important relationships.



Simulation as a design development tool

One of the specific areas in which this simulation programme has been used is in improving the design of automatic implement control systems.

The purpose of the draught control system fitted to tractors is to maintain the implement draught force at a constant level. It achieves this by sensing, most commonly, top link force, sometimes lower link force and in one case driveline torque. In regulating implement draught force it follows that implement depth will also be controlled, the extent depending on the homogeneity of the soil. If the draught control were 100% efficient, so that the draught force remained constant independent of tractor motion or soil variability, we would not have a dynamic problem and we might expect steady state performance predictions to be essentially the same as dynamic predictions.

However, present draught control systems not only fail to be 100% efficient but there are many conditions in which their performance is considered so unsatisfactory that the operator overrides it by manual control of the implement. Improvements to draught controls performance would therefore,

(a) extend their range of adequate operation to relieve the operator of the burden of manual control.
(b) reduce the work rate loss figure of 8—14% quoted in the previous section,
(c) remove one of the constraints preventing the use of higher tractor speeds.

The research work into control systems is explained in detail elsewhere[10-12]. Here, it is only possible to outline the conclusions reached as a result of using the simulation programme as (a) a testing bed for new ideas and (b) for fine tuning of parameters to optimise control performance. But firstly, an important point should be made, one which is not immediately obvious and is not applicable to all control engineering problems. The draught control system cannot be optimised in isolation. It must be incorporated as an integral part of the tractor-implement system. Careful thought about the various interactions that occur will show that this is true. To take just one example, the rate and magnitude of control operations affect the nature of the transient weight transfer to the tractor. This in turn affects tractive effort, wheelslip and ultimately rate of work output. A strategy for optimising the control that ignores these interactions may therefore be inadequate.

Hence, for this type of real life problem, existing control theory can play only a limited part and simulation may be a more appropriate technique.

Briefly, the general conclusions reached on control systems were as follows:

i) Top or lower link sensing systems have an inherent instability problem if the sensitivities are increased. Their performance in the stable region has now been optimised through simulation.

ii) Driveline torque sensing inherently involves a longer delay time than force sensing control but can be made to operate satisfactorily if linkage position feedback is incorporated.

iii) A similar comment applies to wheelslip or engine speed sensing which have been evaluated in simulation form only.

iv) From the model predictions, pure draught sensing control has the most scope for improvement. Although there are practical difficulties, eg reduction of delay time in hydraulic systems, it could reasonably be expected that the dynamic losses could be halved by using an improved control design.

v) Such a control would require a facility for altering parameter values, eg rate of lift, deadband etc. to their optimum values for a particular condition. In fact, strategies for the automatic selection of the optimum control parameters have been predicted from the simulation model. With the present level of microprocessor technology these could already be incorporated in a tractor draught control system.

A further use of this simulation programme is in providing data for other studies. For example, the simplest method of assessing draught variation is to calculate standard deviation, and it was found, having run the programme through a series of various conditions, that the results followed a pattern and could be expressed "empirically" as,

standard deviation

$$= \frac{NH}{1550} (2.50 + 4.15 v^2) \quad (4)$$

where N = number of plough furrows
H = specific draught (N/m^2)
v = forward speed (m/s)

This expression was calculated for a medium power tractor on a typical uneven field surface, and the boundary values of the parameters must be restricted to reasonable values if the equation is to have any practical significance. As a rule of thumb guide it was then found that maximum dynamic work rate occurred at a pull value of (1.5 x standard deviation) N lower than the maximum steady state work rate. Attempts have been made to incorporate this type of information in tractor/implement matching programmes which have previously ignored the effects of dynamic losses.

Conclusions

Simulation modelling is a powerful computational tool available to the engineer for solving engineering dynamics problems.

The prediction of tractor-implement field performance is described as an example of the type of problem which has successfully been addressed using this technique.

Two examples are discussed to show how simulation contributed to the improved design of control systems and to our understanding of how a tractor-implement combination responds to draught variations.

The field performance of tractor-implement combinations in terms of actual work rate is 8 to 14% lower than that predicted using steady state assumptions.

An empirical formula based on measured and simulated results is given to predict the draught variation under typical field conditions.

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Machinery and equipment in cereal harvesting, drying and storage

V J Feeney and D J Greig

Summary

AN examination of trends in cereal production in the UK reveals that pressure is being placed on grain processing systems and that this is likely to increase.

The major source of variation in cereal production from harvest to harvest is the weather and so when modelling the process this is an important consideration. The modelling of the moisture content of standing grain is possible and this highlights the large variations within years, a good year for one acreage may not be for another.

Differing criteria may be used to judge investments, but those which do not take account of the level of risk associated with the investment, and the attitude of the investor towards it, do not give a full picture. Risk spreading may be achieved in several ways and the pressure leading to increased storage requirements may change the traditional on-farm cereal processing techniques.

Trends

IN assessing harvesting drying and storage requirements trends in production should be examined to reveal areas most likely to be affected in the foreseeable future. There has been an increase of wheat and barley production due to better varieties and improved technology. These, in conjunction with higher prices, have improved cereal profitability relative to other enterprises.

Wheat and barley have exhibited 2% and 1.7% compound yield increases respectively since the war, (table 1) though this may be slowing, especially in barley. The area grown has also increased, (table 2) but growth has virtually halted due to near exhaustion of suitable land.

Structurally there has been a greater concentration of the industry (table 3). In England and Wales in 1965 20,000 growers grew over 100 acres and represented 61% of the cereal area. By 1977 this number had increased by 3000 and represented 77% of the total. Another shift has been towards specialisation in one of the crops. In 1965 4400 farmers had over 100 acres and represented 36% of the area. In 1977 it was 8000 farmers growing 65% and similarly for barley in 1965 1100 farmers grew 48% compared to 14,500 in 1977 who grew 62%. In addition there has been growth in the number of farmers with over 200 acres. This trend of concentration within the land available could continue and if yield continues to increase would place larger burdens on established cereal growers of 200 acres or above. This rate of expansion is 2%/a. and this, coupled with possible yield increase of 1.5%/a., would result (if ratios of wheat and barley areas stay constant) in 1984, in an additional 1.8 M tonnes of grain, which would amount to around 150 tonnes per farm[1]. The Cambridge survey[2] suggests that to bring farm storage up to a level to deal with seasonal variations this figure may be doubled.

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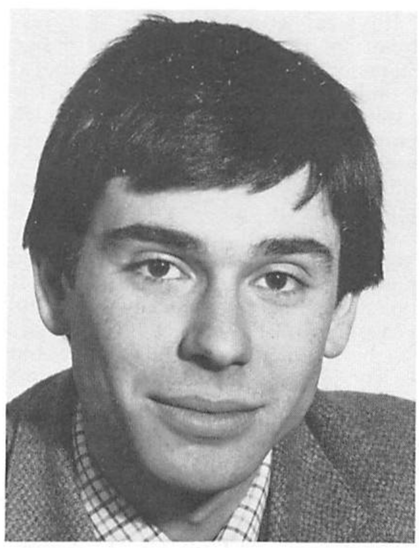

V J Feeney

There is already pressure on grain storage in that between 1975-79 grain production went up by 3.3 M tonnes whereas MAFF suggest storage increased by only half this amount. This creates a larger managerial burden in making strategic decisions. These may often be based on imperfect knowledge of relative (machine) performance and costs of the system's constituent members. Where information is available at all, it will not be given over a range of conditions and so be of little use to the investor.

Capacity

Capacity in this instance can be looked on as the amount of crop harvested in a given season. The capacity is a function of two things:

(1) the rate of work achieved

(2) the length of time available.

Both of these have physical, biological, environmental and managerial limitations characterising them.

Rate of work

The physical considerations of the machine are chiefly its specification and performance. The former characterised by width and straw separating area the latter by gear selection and speed. In the longer term work rate is dependent on the service needs and adequacy of servicing available. (The frequency of repair on the other hand is chiefly an age dependent process).

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The interaction of the machine's physical characteristics and its operating site determines the characteristics of its operation and hence work rate. The machine design compatability with a given field condition decides the work rate for that site. The design quality and age determine reliability and hence repair frequency. Quality again is important in determining the operator's willingness and/or ability to employ full physical capacity.

The other physical characteristics are the land's; its topography, size and shape and the ancillary equipment. The effect of these is related to the machine in that they will be different in magnitude for each machine.

Table 1 UK cereal yields

	Wheat tonnes/ha		Barley tonnes/ha	
	Actual	5 year rolling average	Actual	5 year rolling average
1945	2.4	2.4	2.4	2.2
1947	1.9	2.3	2.0	2.2
1949	2.8	2.4	2.6	2.3
1951	2.7	2.5	2.5	2.4
1953	3.0	2.8	2.8	2.6
1955	3.4	2.9	3.2	2.7
1957	3.2	3.1	2.8	2.9
1959	3.6	3.3	3.3	3.0
1961	3.5	3.4	3.3	3.1
1963	3.9	3.8	3.6	3.4
1965	4.1	4.0	3.8	3.6
1967	4.2	4.0	3.8	3.7
1969	4.0	3.9	3.6	3.6
1971	4.4	4.1	3.6	3.5
1973	4.4	4.2	3.9	3.7
1975	4.3	4.4	3.4	3.8
1977	4.9	4.5	4.2	3.8
1979	5.0 (est)	4.7	4.2 (est)	3.9

Source: MAFF

Biological influences can be considered as characterised by yield and state of husbandry. The type and variety having an influence upon the yield, the husbandry influences rate by the incidence of weeds, evenness of the crop and degree of lodging. These are determined by the crop maturity and the operating timing.

The weather has a direct effect upon work rate by its influence on the rate of pick up. Drying is also directly dependent upon the grain mositure content which is subject to the weather.

Management's decisions directly effect the rate of work by his knowledge and assessment of conditions and risk.

The considerations which make up the risk are those of losses, either failing to finish harvest or through lack of thoroughness, market conditions and alternative commitments all of which can be 'traded-off' against each other.

Though subject to the same classes of influences each has a change in relative importance.

Physical considerations are less important though the machines design characters will effect the operational period through its reliability. The system's ability to deal with crops of high moisture content will also determine workable hours.

The biological conditions are of greater importance. It can be considered that from the onset of 'harvest maturity' the crop is subject to losses of yield and quality, the rate of this is variable and sets a limit on the economically successful harvest length. The impact of these losses can be lessened by seeding policy and variety selection, but it is still the most constraining of influences.

Weather is closely interactive with the biological tolerance of the crop. The pre-harvest weather determines the harvest commencement, all other things being the same, and from then on determines the hours in which the crop is workable both from the point of view of the trafficability of the soil and crop moisture content.

The time allowed is also dependent upon managerial decisions in consideration of energy use, operator fatigue, cost of labour and losses and conflicting calls upon the limited farm resources. Market prices and conditions also influence the allocation that management makes for harvest.

Weather

The influence of the weather in cereal harvesting gives rise to large variations in work-rate, time available and hence the capacity of the harvesting, drying and storage needed for a particular season. The modelling of its influence can give a clearer picture of the trade-off between drier, combine and wet storage capacity.

Standing grain moisture contents

In the past influence of moisture content changes have been considered to be independent of weather[3] as the relationship between weather variables and moisture content had not been established. Models of this have subsequently been put forward. Smith (1979)[4] examined four approaches to the relationship in barley during rainless periods. These were:—

1. An empirical drying equation[5,6]
2. M-Me decreasing exponentially with time
3. Crampie and Dalton's dry weather model[7]
4. Diffusion theory model[8]

A comparison of these models revealed that model 2. was not satisfactory and that all could be improved by adjusting the parameters for broader ranges of temperature and moisture content. The remaining three models gave equally satisfactory predictions, the empirical model having the advantage of simplicity over the diffusion model, and its parameters can be reliably calculated under laboratory conditions and will not have as much regional variation as Crampie and Dalton's, as suggested by van Elderan and van Hoven[9]. The other advantage of the empirical model is that it is based upon known physical principles and is hence more readily improved. This now allows the more accurate modelling of the time available for combining subject to an upper constraining moisture content during dry periods. Wet periods can be defined as those having more than

Table 2 UK cereal production

		1960	1965	1970	1975	1976	1977	1978	1979 forecast
Wheat	Yield: t/ha	3.58	4.07	4.19	4.34	3.85	4.90	5.26	5.13
	Area: 000 ha	850	1026	1010	1034	1231	1076	1257	1371
	Production: 000' tonnes	3043	4176	4232	4486	4740	5274	6614	7030
Barley	Yield: t/ha	3.16	3.75	3.35	3.63	3.51	4.39	4.20	4.13
	Area: 000' ha	1365	2183	2243	2345	2182	2400	2348	2347
	Production'000' tonnes	4317	8192	7516	8505	7658	10531	9850	9690
Oats	Yield: t/ha	2.62	3.01	3.25	3.41	3.23	4.06	3.93	3.94
	Area: 000' ha	767	408	375	232	235	195	180	133
	Production: 000' tonnes	2090	1229	1219	791	764	790	708	525
Total cereals	Area: 000' ha	–	–	–	3654	3685	3706	3811	3873
	production: 000' tonnes	–	–	–	13937	13264	16726	17268	17320

Source: MAFF

Table 3 Structures of cereal area: England and Wales

	1960	1965	1970	1973	1977
WHEAT					
Farms growing more than 100 acres (40 ha)					
No holdings	3099	4441	4871	8714	7740
as % total holdings growing wheat	0.9	6.8	11.3	19.5	20.7
Area: ha	211401	311948	367390	751192	680742
as % total wheat area	26	36.5	46.2	62.7	64.5
BARLEY					
Farms growing more than 100 acres (40 ha)					
No holdings	6817	11029	14892	12819	14502
as % total holdings growing barley	2.1	10.3	17.2	16.4	19.6
Area: ha	502289	857913	1231296	1033375	1199341
as % total barley area	40.6	48.4	59.5	57.1	61.8
TOTAL CEREALS					
Farms growing more than 100 acres (40 ha)					
No holdings	–	20047	22967	23121	22746
as % total holdings growing cereals	–	14.9	22.4	25.8	27.6
Area: ha	–	1745956	2226771	2413219	2422723
as % total cereal area		60.6	70.7	74.8	76.5
Farms growing more than 200 acres (75 ha)					
No holdings		7475	9913	10912	11946
as % total holdings growing cereals		5.6	9.6	12.2	14.5
Area: ha		1046130	1481147	1714437	1830610
as % total cereal area		36.3	47.0	53.1	57.8

Source: MAFF

0.05 ins. in a given day and hence no combining activity taken place.

High temperature drying can be considered largely independent of ambient conditions, merely depending upon the grain moisture content.

In low temperature drying the ambient conditions i.e. temperature and relative humidity have a major influence upon the drying rate. Hourly data is available to arrive at frequency and joint frequency distributions of these variables. These can be used to simulate the conditions and thus leading to conclusions and rules for controlling ventilating periods and predictions of the rate at which moisture will be removed.

These ambient conditions also effect the rate of damage caused by micro-organisms in wet grain, this is not sufficiently understood to model at the moment, and so any grain which could not be handled within what is considered as a safe period could either be charged for at contract drying rates or written off. The degree of variation between periods, due to the weather, that a given system can handle is large. For example, using a system as set out in table 4 it was found that 60 tonnes of crop could be harvested in a 10 hour period with grain at 19% m c and only 36 tonnes in the same time when it was at 30% m c. Because the drying capacity falls when the grain moisture content increases, the usage of the wet storage increases to a point where it becomes limiting to the unloading of vehicles, and hence the harvesting operation becomes less efficient.

In studies by Van Kampen[10] and by Donaldson and McInerney[11] the former found in Holland the average period available for harvesting wheat was 10 days ± 7 days, the latter showed the average to be 22 days and the least to be 15.6 days in the UK so there is a high risk of having capacity either underused or overstretched in any given season. Further, the amount of grain to be harvested in any given year determines which year is best in terms of the length of harvest for any given system, so because a particular year gave rise to the shortest harvest period for one yield of grain, it does not follow that this will hold true for other levels of yield. This can be seen in fig 1.

Table 4 System used

Combine		*Delivery*		*Grain Facility*	
No	1	No	1	Continuous flow drier cap t/hr	4.3
Potential harvest rate t/hr	6.5	Hauling cap t	2	Wet holding bin cap t	18
Tank t	2	Max unloading rate t/min	2	Overflow bin cap t	6.4
Unloading rate t/min	2	Travel time (one way) min	9	Receiving pit cap t	2
Set up time min	½				

Capacity considerations

In any given year the capacity of the harvest system may be inadequate where the quantity of crop exceeds the machine capacity for the time available. The situation of excess can be investigated at two levels. The first is that of intermediate excess where the quantity to be harvested is less than the capacity of the system but in excess of the next smallest system. This arises from the lumpiness of the system composition and is not a situation of capital investment being wrongly made. It becomes apparent that an exact match of the system to the crop is unattainable though it may be more closely approached by large scale machinery sharing or centralised processing. Secondly, there are however cases where the system is clearly in excess and where a smaller system can be found to complete the task. This should not be necessarily considered an error on the investor's part, as his decision in the face of risk depends upon his attitude in the medium term and his expectation of the harvest. Donaldson and McInerney found in a survey that discrepancy between capacity and harvest was biased towards excess in the average year, but if the capacity was for the worst harvest expectation of a ten year period, then the number of cases of excess capacity in any real sense had halved. When modelling this process the propensity of investors to take account of the worst eventuality must be considered and the effect this has on total harvest costs evaluated. The cost of selection of capacity in excess of needs can be looked on as the opportunity cost of that capital and as such it may prove a reasonable policy. This can be done by examining the average cost curves of the system or parts of the systems. This reveals the opportunity costs of over investment which diminish as the area harvested

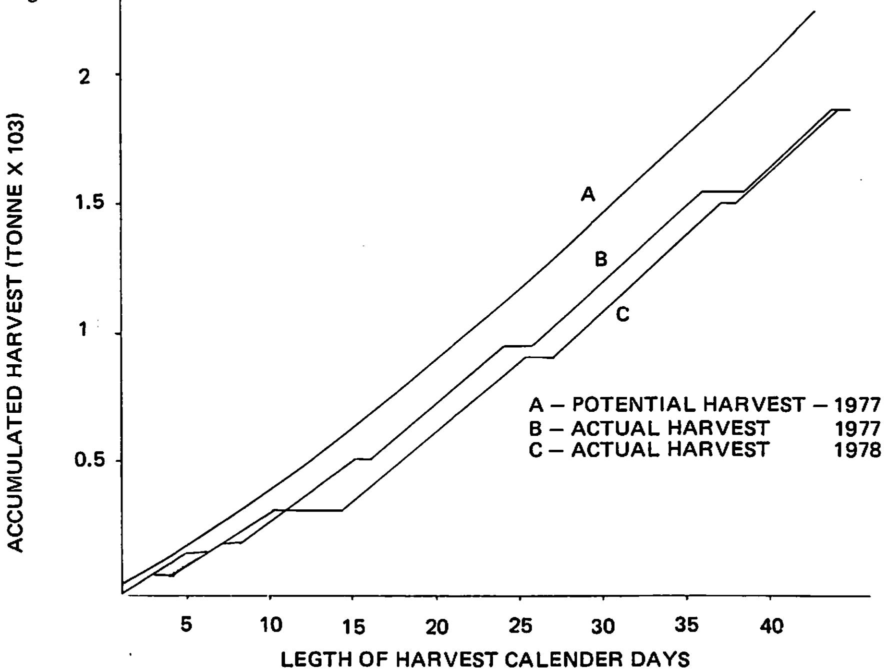


Fig 1 Accumulated amount harvested as related to length of harvest.

increases. Further, over investment may free management time for critical tasks and the cost/benefit of this can be evaluated.

In appraising investment strategies, it is often assumed that certainty or risk cannot be quantified. The uncertainty faced by the decision maker when considering grain harvesting drying and storage is chiefly due to weather. This can be dealt with using a statistical measure and probability distributions can be constructed. This places the investor in the position of facing an insurable risk. The problem is further complicated by the uncertainty of prices of both inputs and products which are at best only subjectively assessed, being based on experience and limited information. Any project then will have a set of possible outcomes that can be described by a distribution but that distribution is bound to be to some extent uncertain. One approach is to assume that only those influences which can be assessed objectively, in this case the weather, effect the project while all others are held constant.

Whether by assessing only objective influences or by taking account of the limited information available on other influences, a distribution will be calculable for each project of its probability versus return. Two examples might be (fig 2)..

A system A has a lower return associated with it but the lowest possible return from it is higher than B. If there was a lowest acceptable return to maintain the farm or allow further inputs to be bought then A would be the chosen system.

In fig 3 the selection of a system would again depend upon the investor's criterion. On the basis of the more probable outcome, D would be favoured but C has a high expected value ie the product of the probabilities of each outcome and the yield. If again the investor had a policy of minimising the worst outcome, a minimax solution, or in th case maximising the minimum gain, a maximin, D would become the chosen system.

Sensitivity analysis may be used to identify the probability of a particular level of return lying between specified levels of acceptability to the investor. This would not be available using a deterministic approach.

Looking at the investment in harvesting and drying equipment yielding a cash flow for n years, its present value can be represented by

$$P\,V = \sum_{j=o}^{n} \left[\frac{Xj}{(1+1)^{j}} \right] \quad \begin{array}{l} i = \text{interest} \\ x = \text{random flow} \end{array}$$

i can usually be considered uniform through the whole period. As Xj is random so therefore is P.V. and has an expectation. If all Xj are mutually independent random variables having variances and expectations

$$\Sigma \quad \frac{X}{(1+1)^{j}}$$

will be normally distributed and if j becomes efficiently large P V values can be obtained from using normal distribution tables[13]. The variance can thus be used as a measure when examining the likely value of Xj.

It has been postulated[14] that a normative model of investment may be constructed using the present values of the different possibilities as coefficients in the objective function and the covariance as a matrix of constraints, and hence arrived at a policy to maximise the present value of a portfolio and minimising the variance. This gives an efficient portfolio selection, in this case the single selected 'security' would be the harvesting drying and storage system.

Risk and decision policies

When considering the problem of investment in the harvesting system attention should be given to the type of criterion used to judge the set of possible

Fig 2

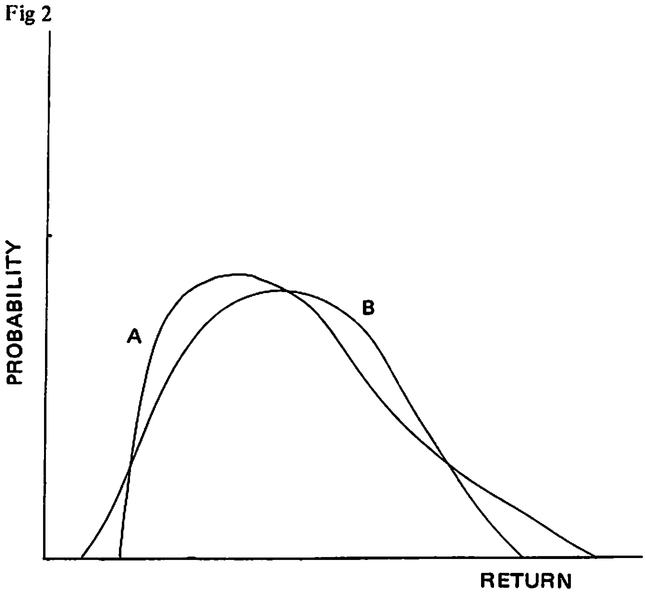


Fig 3

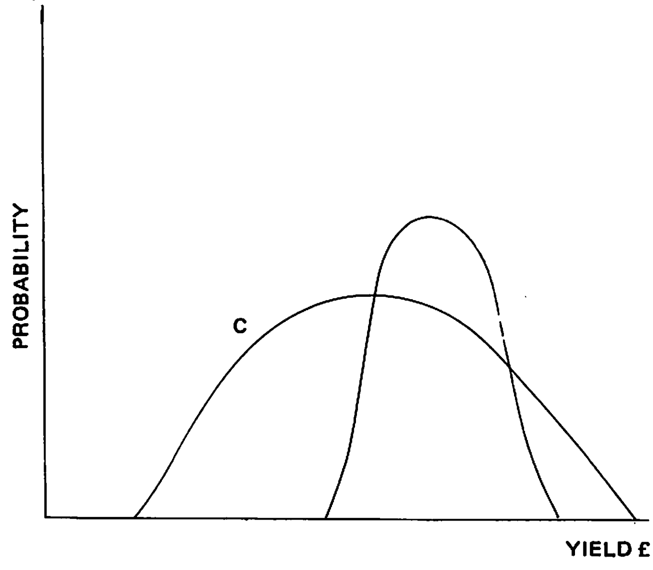
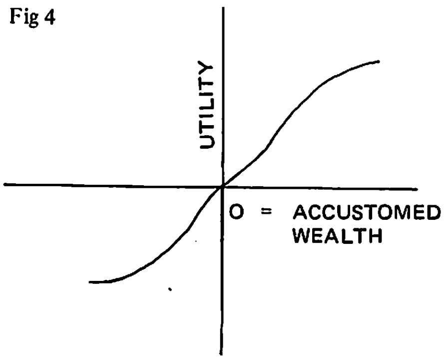


Fig 4



outcomes which a probalistic model would generate.

An assumption is made from the outset that any investor in this system can be considered rational and at some level of wealth, risk averse and who can be characterised by the utility function in fig 4.

For levels of wealth above that present accustomed level it is first concave and then convex[15]. Likewise for levels below the present one it is characterised by the curve to the left of the origin. In general, people are assymetric in the level of utility gain or loss for the same change in wealth and so it is likely the curve falls faster to the left than it rises to the right.

To avoid the St Petersburg Paradox it is bounded above and below.

This utility function implies that at some stage the investor will obtain decreasing amount of utility for each extra unit of wealth added. This assumption about the investor implies that he is risk averse in the case of high investment, and therefore is placed to the right of the point of inflection in fig 4. It is also assumed that for a given level of wealth the investor is consistent in his choice of investment and hence, risk that he is willing to take.

It is worth noting that during the length of the harvest the management attitude to risk may change and that for making day to day decisions, he may tend toward risk neutrality, particularly at the end of the season when the possibility of failing to complete the harvest becomes more likely. This change in attitude is not contradictory to the assumption made with regard to investment, rather it may go some way to explain it. The investor having seen over perhaps several seasons a system failing to complete the operation, will be inclinded to invest in a system which is more likely to complete it. In terms of a probability distribution as in fig 5 he is at least attempting to push the whole frontier outwards and ideally steering his own distribution rightwards as well. The type of policy then followed by the investor though never explicitly stated may be characterised by one of the following strategies.

The most conservative of policies is one that, examining the possible conditions that may face him, he pursues a policy of determining the worst that can possibly happen and then picks a strategy whose most unattractive contingency is least disastrous. This is the maximin approach.

A further policy might be the Bayes criterion of applying subjective or equal probabilities to the possible outcomes. Unlike the maximin policy this would take account of all the possible payoffs, but has the serious limitation of an arbitrary weighting of unknown outcomes.

A more satisfactory strategy, though more difficult to apply, is to concentrate on the opportunity cost of an incorrect decision.

In order to protect against heavy loss, the investor may now apply a minimax criterion to a matrix of opportunity costs of the possible systems, ie choose the policy which has the smallest of maximum opportunity cost or regret. This does take account of large disparities between intermediate payoffs between strategies but it still ignores the intermediate pay off within them, concentrating solely on the highest figure. It may also be considered that neither the actuarial value nor a cardinal utility measure of the Neumann-Morgenstern[16] type is appropriate as measure of regret for an incorrect decision as the differences become small.

Another criterion which could be used and which may be modelled, is one which makes some measure of the efficiency of the investment. An investment can be considered inefficient if it is possible to obtain high expected, or average, return with no greater variability in return, or the corollay, obtain a greater degree of certainty with no decrease in average or expected return.

The purpose of a model to evaluate the harvesting system would be to maximise the expected return and minimise the variance.

Graphically the situation would be in a three security case of portfolio selection as shown in fig 6. The lines E are iso-mean lines representing equal expected returns and the ellipses V represent equal variance ellipses. From the criterion of maximising return for minimising the variance it is apparent that this condition is fulfilled where the variance becomes tangent to the line of equal expected returns. All these points will lie on the line a.a which is termed the critical line. If a point is on the critical line it minimises the variance for some value of expected return.

Generally an investment portfolio would be selected by investing a fraction of the total budget in each of some or several possible securities each with an associated return expectation and variance. In the case of the harvest system the investment will be in one 'security' with only one distribution of return, from amongst the different possible systems. A further consequence of investor's attitudes towards risk and expected revenue would be that for every level of utility there would be a locus of points of indifference between risk and the level of income.

Implications

If the criterion of evaluating the expected return and its variance is employed these two strategies emerge:—

1. Many on-farm systems tending towards over capacity
2. Fewer centralised driers and stores spreading risk and lowering unit costs

The larger enterprises have the

Fig 5

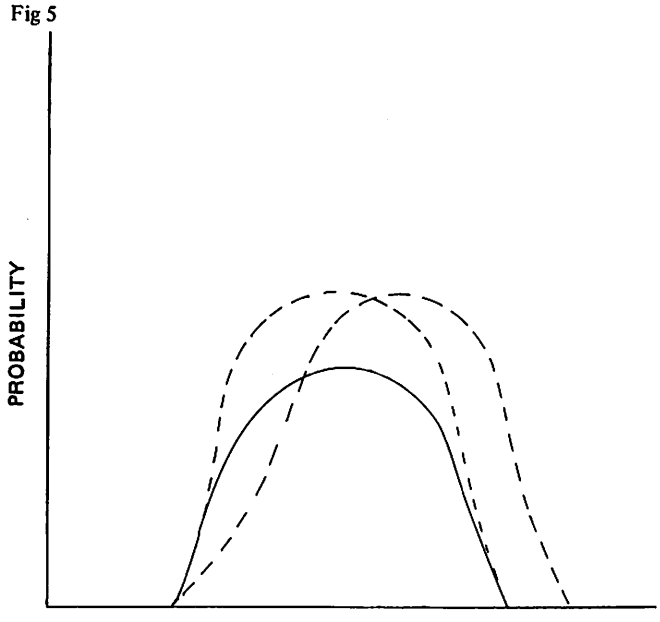
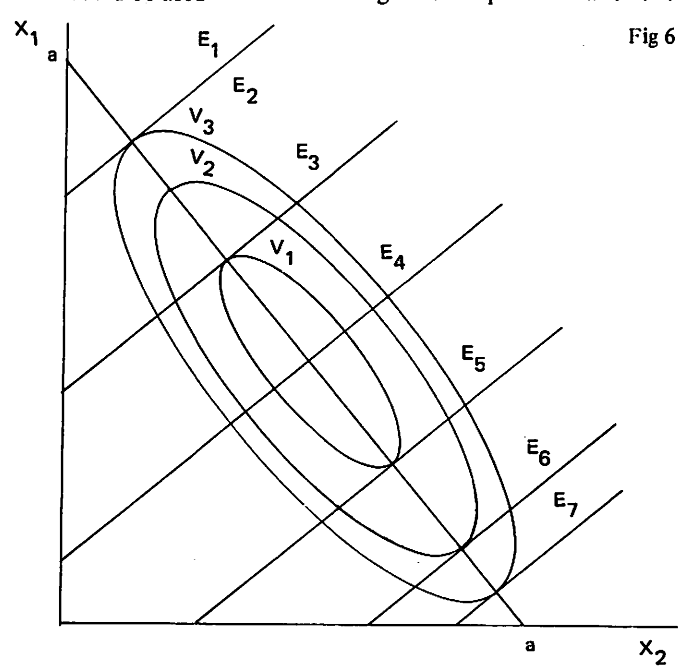


Fig 6



advantage of being eligible for larger FEOGA grants and so the cost per tonne is lowered further, for example an 18,000 tonne store and 20 t/h drier after FEOGA grant cost £12/t, a 200 tonne silo storage/drying system would cost £19/t and up to 900t around £42/t. Any model dealing with investment appraisal must take account of fiscal policies which radically alter the attractiveness of differing policies.

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Irrigation: The way ahead

AN interesting new venture got under way when the UK Irrigation Association held its inaugural conference at the National College of Agricultural Engineering on 15 October 1980.

The Association aims to promote interest in the subject, to collect and exchange information and to raise standards of competence in design, installation and management.

Some 260 delegates heard four technical papers from USA, France and Israel and had a glimpse into the future for the UK through the eyes of Sir Nigel Strutt the former Chairman of the Advisory Council for Agriculture and Horticulture responsible for the recent report on "Water for Agriculture: Future Needs".

Professor Jack Keller from Utah State University opened the Conference with a very good humoured paper in which he traced the progress of irrigation in the USA. Traditional surface methods still represent about 80% of the total with sprinkler and trickle systems going through interesting and exciting development phases and contributing the other 20%. Current research is very much geared to cutting back on energy use.

European developments were discussed by Mr Eddie Bailey who is involved with his own company in Paris. The choice of base was no accident since France has lead the way in Europe in irrigation developments. These technical developments tend to have been based on USA and Israel experience but many companies making equipment have come and gone as a result of marketing untested equipment. Often in Europe the basic technical requirements of installations have been subservient to labour saving, price and fashion.

Present day practice and current developments in Israeli irrigation formed the theme of the paper by Professor Gerald Stanhill from the Institute of Soil and Water in Israel. Israel has all the problems of a low rainfall area but has tackled the water supply problems in its own normal dynamic fashion. The Sea of Gallilee, which is 200 metres below sea level, and a coastal aquifer system provide the water for a national grid. This is achieved at a very high energy cost. Farmers are of course in competition with others for this scarce resource and its use in agriculture is justified by developing very high export value crops and importing low value cereals. There is a high extension service input to get the best from irrigation and the cost of this is shared by farmers and government.

During the last decade there has been a very rapid expansion in the area receiving drip irrigation in Israel. Extravagant claims were made for increased water use efficiency with this system although research has shown that it has no clear advantage over good sprinkler practice except in particular cases; these have related to brackish (i.e. containing salt) water and to crops whose leaf canopies are especially sensitive to wetting. The reasons for the expansion in drip systems are probably to be found in its suitability for automation and the utilisation of sloping or awkwardly shaped fields. These systems are very often computer controlled to a greater or lesser degree of sophistication.

Treated sewage water will soon be contributing one tenth of Israel's agricultural water consumption. This obviously necessitates monitoring for health and pollution hazards and as a consequence is not used on crops for human consumption.

Dr Marvin Jensen, National Research Programmed Leader in Water Management in Maryland, USA discussed the development of on-farm irrigation management practices in the USA. He sketched in the background of irrigation developments of the different regions of the US in terms of the increase in the practice of irrigation and also by type of installation.

Drought cycles lasting several years in a region seem to be another major stimulus causing expansion of irrigation as did more dependable automatic equipment, electronic controls and the centre pivot system of application which enables uniform applications of small amounts. Albeit this latter system misses a substantial percentage of the land.

Irrigation scheduling has become very important in the USA. This predicts the time and amount of applications, allowing for expected precipitation, available water, evapotranspiration and the capacity of the system. This scheduling is generally done by commercial management services using sophisticated information gathering and disseminating techniques.

Sir Nigel Strutt wound up the papers with a contribution which included many verbal darts aimed at a wide variety of targets ranging from the highest in the land to water authorities. The report from the Committee which he chaired predicted a quadrupling of demand for irrigation water by the end of the century. The Committee pointed out that England and Wales were not short of water but that it required redistribution. It also criticised the British Farmer for being slow to recognise the needs of plants for water. However, there is now improved knowledge of the interaction of soil and water, of moisture stress and the varying water requirements depending on stage of growth. Also of course there is better equipment to do the job.

Sir Nigel concluded that irrigation will of necessity become more important, can bring large rewards and consequently is a good investment. EEC pressures will demand that the right crop is grown in the right place and there will be no place for low yields from soils which, if irrigated, could do much better.

Further information about the Irrigation Association and copies of the Conference papers, which will be available by early 1981, can be obtained from Dr M K V Carr, Honorary Secretary, c/o National College of Agricultural Engineering, Silsoe. *J G S*

Tractor overturning accidents and safety cab strength

C J Chisholm

Summary

TESTING of tractor safety cabs ensures that they will be strong enough to protect a driver in any overturning accident in normal agricultural circumstances. But what are normal circumstances and how are they related to strength test criteria? This article summarises research, involving computer simulation and overturning experiments, aimed to help answer these questions.

Introduction

LEGISLATION was introduced in the UK in 1968, and came into force in 1970, requiring new tractors to be fitted with approved safety cabs. In the decade since then the number of drivers killed in overturning accidents had steadily decreased as safety cabs have become more common on our farms, and the safety cab strength test standards on which the legislation is based have undergone a process of gradual development. The standard tests normally involve hitting the safety cab with a pendulum whose impact energy depends on the weight of the tractor. Research carried out in Sweden in the 1950s, and subsequently updated by other studies, forms the basis of this relationship between energy and weight. To pass the test the cab must not intrude into a defined zone of clearance around the driver, or leave it unprotected, after deformation under the pendulum impact. National and international standards committees are at present developing alternatives to the pendulum test, which involve instead a slowly applied force, generally referred to as static testing. Although this is not quite so realistic in simulating accident conditions it has advantages of repeatability, and of providing more information for safety cab development and research.

From the outset, test methods have been designed to ensure that safety cabs provide a very high level of protection — something approaching 100%. To do this without making cabs unnecessarily strong and costly requires a detailed knowledge of how they perform in overturning accidents. Some information was gained from a study by the National Institute of Agricultural Engineering (NIAE) under contract to the EEC Commission in which the deformation of safety cabs on tractors involved in overturning accidents was compared with that in corresponding standard tests (Chisholm and Seward, 1976). From deformations quoted in accident reports it was possible to estimate the amount of energy absorbed in the cab, and this was found to be greater than that absorbed in standard tests in only about five per cent of the 160 accidents analysed (fig 1). In two accidents the deformation was so great that the driver would probably have died if he had been in the cab. In one of these accidents the driver jumped clear; in the other the driver was not on the tractor, which ran away when parked. The lack of guidance may have contributed to the severity of the damage in this case.

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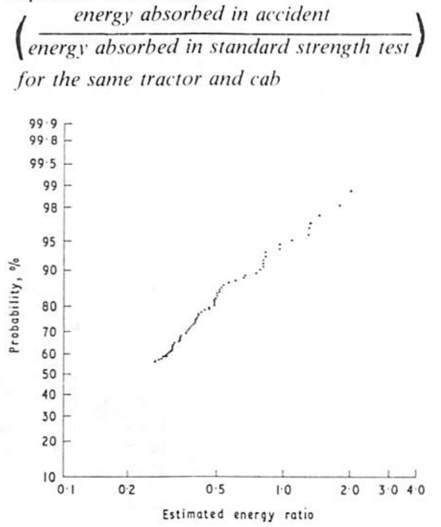
Unpredictable variation in tractor behaviour can cause great differences in the damage resulting from severe accidents. In extreme cases it is possible for very large amounts of energy to be available for cab deformation even when the circumstances of the accident are not abnormal. For this reason, although cabs offer such a high level of driver protection it is very difficult to predict, from studies of this kind, the relationship between protection and energy applied in standard tests at this extreme level of probability, say between 99% and 100%. In addition, the information provides a good overall indication of the adequacy of test criteria but does not show in detail where the criteria may be improved.

To help in establishing these details the NIAE has carried out an extensive programme of research into the dynamics of sideways overturning accidents. Since accidents cannot be observed as they happen it was necessary to simulate them, both by mathematical models and by experiments.

Fig 1 Cumulative distribution of estimated energy absorbed in sideways cab deformation, expressed as the ratio:

$$\left(\frac{\textit{energy absorbed in accident}}{\textit{energy absorbed in standard strength test}}\right)$$

for the same tractor and cab



To find out which kinds of accidents were most important and likely to lead to the greatest safety cab damage, the investigation began with a survey of dynamic behaviour in real accidents. The study was restricted to sideways overturning accidents, since rearing accidents are much less common and have been the subject of much other research.

Overturning accident types

The survey concentrated on the dynamic behaviour of the tractors and the conditions in which the incidents occurred (Chisholm, 1972). In particular it was hoped to establish whether there was a significant probability of a safety cab hitting the ground before the side of the rear wheel, thereby absorbing a large proportion of the available energy. This important case formed a major part of the original Swedish work and of other studies (Moberg, 1964; Watson, 1967), and is represented in fig 2 (a). No accidents of this type were found in the survey but a similar type illustrated in fig 2 (d) was found to be fairly common. We were not able to establish whether the cab would have hit the ground first in these accidents but there was a possibility of this happening in some of them. The other major types of accidents found are shown in figures 2 (b) and 2(c). It was concluded that the most severe types were those in which tractors fell off steep banks and those involving multiple rolls from a high initial speed. It was also shown that

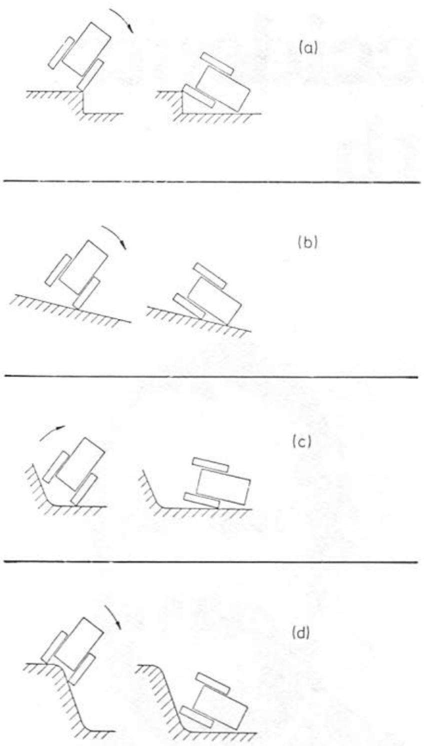


Fig 2 The effect of ground profile on overturning:
(a) Tractor tips off bank, wheel remaining on edge; (b) Overturning on flat ground, either level or with a uniform slope; (c) Overturning initiated by tractor mounting bank or large obstacle; (d) Overturning initiated by tractor falling over edge of bank or into ditch.

in about 20% of accidents, cabs struck non yielding surfaces such as roads. Although the heights of the banks down which the tractors fell were generally given in the accident reports, the slopes were not always accurately described. The highest banks quoted were about 10 metres, but these were probably of such gentle slope as to be represented better by fig 2(b) than 2(d). There was evidence, however, to suggest that overturns down steep banks between two and three metres high were sufficiently likely to warrant study.

Computer simulation

A number of previous studies have included mathematical analyses of overturning and impact behaviour. Most of these have been concerned either with stability or with impact, and few have combined the two or validated the analyses by experiments (reviewed by Chisholm, 1979 a). While some of the mathematical models of stability have been quite sophisticated, most of the impact studies have assumed that the various impacts between parts of the tractor and cab and the ground can be represented by pure plastic impulses. This allows a first-order estimate of the behaviour to be obtained but is a considerable over-simplification. The mathematical model and computer simulation developed at the NIAE was intended to cover the behaviour when overturning down a bank or during a multiple roll and particularly to provide a realistic description of the impact behaviour in both cases. Furthermore, because of the complexity of overturning accident dynamics it was felt that models must be based firmly on realistic cases and be thoroughly validated experimentally.

The basis of the mathematical model was a treatment of the equations relating the forces and deflections at each point of contact between the tractor or frame and the ground. The forces at the tractor points such as the frame, tyres, and the side of the rear wheel are related to the corresponding deflections by defined structural relationships. The same applies to the forces and deflections at the ground. The tangential force at the contact face was assumed to be related to the normal force by a coefficient of friction, which was not a fixed parameter but a variable which could change continuously according to, for example, the sliding velocity. Finally, the equations of motion governing the rigid, undeformed part of the tractor provide further relationships between the contact forces and the position in space of the tractor centre of mass, which in turn is dependent on the deformations.

The general solution of these equations is made clearer by considering the effects in a computer simulation using numerical integration. At each small step in time the position of the tractor centre of mass and the orientation of the rigid part is known from integration of the accelerations found in the previous step. Each contact point may then be thought of as a series of springs, some representing the tractor structure and some representing the ground, and the solution of the force deflection equations for these springs is straightforward provided that the instantaneous value of coefficient of friction is also known. Thus the behaviour at each contact point may be calculated separately and any number of points in simultaneous contact may be handled at one step. The solution of these contact point equations then provides the forces and hence accelerations on the rigid part of the tractor for integration to give the tractor position at the next step.

In this way the model can handle not only the impact but also the overturning behaviour, since this is governed in the same way by forces due to friction and deflection at the tyres. Tyre frictional force depends in a complex way on a large number of parameters, such as slip angle, camber angle, normal load, and the types of tyre and surface. In addition, when some parameters vary continually the side force does not directly assume its corresponding steady state value but develops the new force gradually as it rolls. This relationship, and the effects of slip angle and surface condition were taken into account in the simulation, and the effects of other parameters were assumed to be insignificant. The model was capable of handling non linear force deflection characteristics,such as the elasto-plastic behaviour of the cab and the rear wheel, and could also include damping terms, particularly important in the cases of the tyres and wheel.

The computer program derived from the model was written to simulate the bank overturn shown in fig 2(d) and the uniform slope case in fig 2(b), allowing for continued rolling. Because the predominant motions in these cases occur in the plane of the diagram, a two dimensional model of the behaviour within this plane proved to be adequate.

Overturning experiments

The main purpose of the overturning experiments (Chisholm, 1979 b) was to validate the computer simulation but in addition they provided results which were useful in their own right. It was necessary to build a special ramp (fig 3) to represent the bank type of accident, in order to ensure repeatable, controllable conditions. The height of the ramp varied from 1.2 metres to 2.5 metres, and plates representing the bank slope were hinged at the top to allow the angle to be changed between vertical and about 45°. Soil and concrete landing surfaces were provided. For some experiments the coefficient of friction between the tyres and ramp was reduced by flooding with detergent solution.

The experimental tractor safety frame was designed to restrict the deformation under impact to four vertical bars at the corners which were replaced after each test. The structural behaviour, which could be altered by using different bar length and diameter, was determined using a simple analysis technique and verified by laboratory impact tests using the swinging pendulum weight (Chisholm and Parker, 1974; Chisholm, 1977). Impact force in each of three directions at both the front and the rear of the frame was measured by tri-axial load cells, and the deformation of the top part of the frame by angular displacement transducers connecting the top to the base. These six force and three displacement signals were transmitted through a trailing cable and recorded on

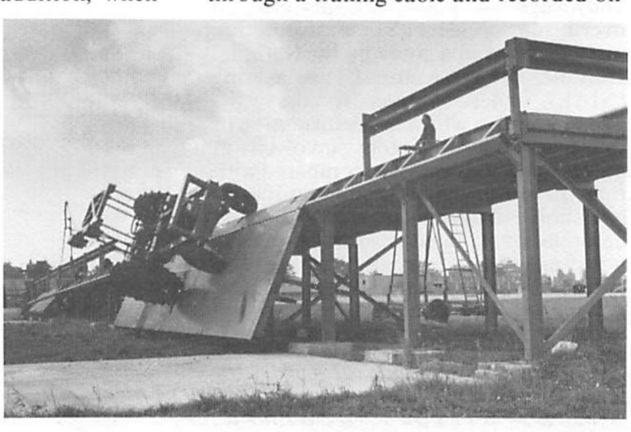


Fig 3 Overturning experiment with instrumented tractor and experimental safety frame

magnetic tape and paper charts in an instrument van for later analysis. The tractor's overturning motion was recorded on cine film from a camera positioned a long way behind it to reduce the effects of parallax, using a telephoto lens. All six coordinates of instantaneous position were derived from a frame-by-frame analysis of the film and velocities were calculated with reference to a large clock in the field of view rotating at one revolution per second.

Altogether 30 experiments were carried out under different conditions of bank height and angle, tractor and frame geometry, ballasting, tyre friction, and ground surface.

Results

There was a good overall agreement between the behaviour predicted by the computer simulation and that measured experimentally. Both the time histories of displacement and velocities in individual overturns, and the variations between overturns with change in parameters showed the same trends in the two cases. The amount of energy absorbed in frame deformation was predicted well considering the complexity of the impact process.

The simulations helped in understanding the way that tyre friction and deflection influences the overturning behaviour. As the tractor slides down the bank it bounces on the tyres and if these bounce motions become sufficiently large, contact at the tyre surface may be lost. If contact is subsequently regained, the frictional side force does not return immediately to its previous value but develops gradually as the tyre continues to roll. Loss of contact early in the overturn has little effect, but later on a point is reached when the resultant of the normal and friction forces at the down-slope tyre passes through the tractor centre of mass. This is a position of dynamic unstable equilibrium and the roll angle at which it is reached depends on the bank angle and the instantaneous coefficient of friction. As the roll angle increases, further the frictional force increases the roll acceleration and reduces the vertical acceleration. If contact is lost at or around this point and the subsequent frictional force greatly reduced, the ensuing motion is very different from that under continuous contact conditions (fig 4). Because loss of contact depends in a very complex way on many parameters, and its effects are so important, the simulation results often showed behaviour which could not be explained in simple terms. Comparison with the experimental results, however, showed that in general the loss of contact behaviour predicted by the simulations was a good representation of what happened in practice.

Better understanding of the impact behaviour was also gained from the simulations (Chisholm, 1979 c). The variations of energy absorbed in the cab with impact roll angle, cab width and track width do not shown rapid changes according to whether the cab or the wheel hits the ground first; rather the effects are continuous because of the duration of impact. As impact roll angle is increased

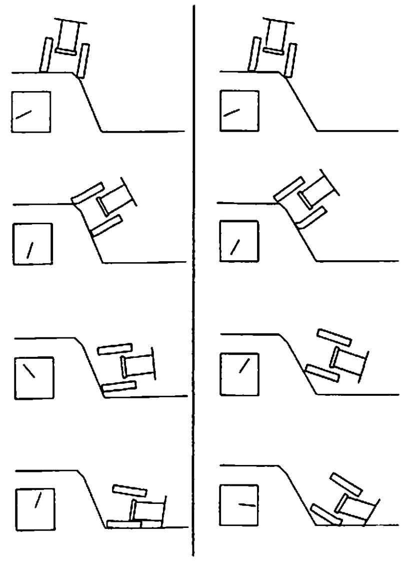


Fig 4 Computer simulation of two tractor overturns down a 2.5 m high bank.

Left:
Bank slope 22½° to vertical. Temporary loss of contact at downslope tyre limits roll angle and velocity at impact — most energy is absorbed by rear wheel. (Diagrams at 0.68, 2.55, 2.89 and 3.06 seconds after start of overturn).

Right:
Bank slope 30° to vertical. Friction at downslope tyre gives higher roll angle and velocity — most energy is absorbed in the safety frame. (Diagrams at 0.69, 2.58, 3.10 and 3.27 seconds after start of overturn).

up to about 110° the energy in cab deformation increases but beyond this the sideways collapse force of the cab makes an increasingly acute angle with the ground and the absorbed energy is reduced. Because the cab impact point is fairly high above the tractor centre of mass, it offers a high resistance to rotational inertia but little to vertical inertia at impact, when the roll angle is around 90°. Thus a large part of the energy due to change in roll velocity is absorbed by the cab, but only a small part due to vertical velocity change. The roll velocity contributes to only a small part of the total initial kinetic energy, however, so although the proportion of rotational energy absorbed is higher the absolute effect of vertical velocity is equally important.

The severity of the bank type of overturn is due to the high vertical impact velocity. The simulations show that only a limited proportion of the energy due to vertical velocity is absorbed in the cab, even when maximum cab deflection is reached before the wheel touches the ground. Structures capable of absorbing only a small part of the total energy do not collapse because of the height of the cab above the centre of mass, and the relatively low moment of inertia and rotational velocities.

This applies only when the vertical strength of the cab is high, which is normally the case in the absence of deformation. Under sideways loading a cab usually forms plastic hinges at the tops and bottoms of the upright members. Deformation then approximates to that of a parallelogram mechanism and the high initial resistance to vertical force becomes smaller as the angle of deformation increases. If the cab becomes relatively weak in the vertical direction, its ability to absorb impact energy due to vertical velocity increases dramatically at high roll angles. Instead of needing rotational inertia to transmit forces of deformation, the cab becomes vulnerable to all the tractor's kinetic energy and the likelihood of catastrophic collapse becomes significant. These conditions would be quite likely to arise in an overturn down a bank more than about three meters high, or in some types of multiple roll accident. The overall probability of this happening cannot be established with any certainty because of the imprecise knowledge of accident conditions, but the evidence is consistent with that obtained from the measurements of cab deformation in accidents (Chisholm and Seward, 1976).

Implications for standard strength test criteria

In addition to being used to find the effect of varying individual parameters, simulations were run with data based on measurements of real tractors. Individual characteristics for a wide range of tractors were not available, but Schwanghart (1973) had published regression lines fitted against tractor mass for the most important parameters, and an updated version of these relationships were used. This averaging of relationships between parameters loses some precision in the simulations but was considered justifiable since mass is the only tractor parameter included in present strength test criteria, and is likely to remain so. In addition, other parameters, such as tyre stiffness, damping, and friction properties, were known only approximately; again, relationships with tractor mass were assumed, in these cases on the basis of simple physical considerations.

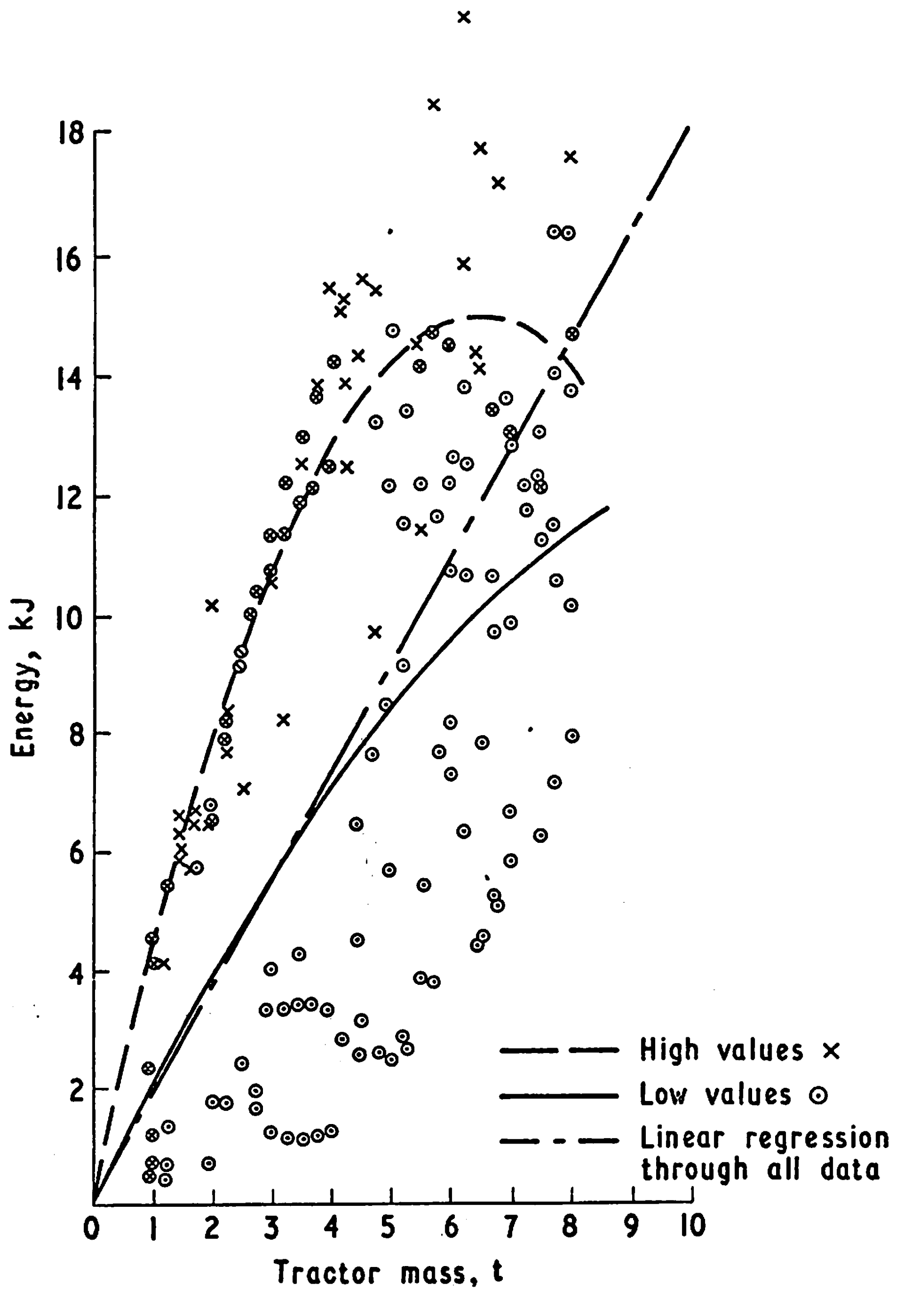
Six standardised conditions were chosen for these simulations, representing bank angles of 0-37½° to the vertical in 7½° steps. It was hoped that this would help to average the effects of discontinuities due to loss of tyre contact. The standardised bank height was 2.25 metres.

Loss of contact was indeed found to have a significant effect and the results were not uniformly distributed within the scatter band (fig 5) but appeared to lie predominantly in two groups, broadly differentiated according to whether or not contact was lost at a critical point in the overturn. The data points were therefore divided visually into two groups and a quadratic regression fitted through the higher group is shown in the figure, together with a linear regression through all points. The shape of the upper group of points and the curve fitted through them indicate that the energy absorbed in sideways deformation of the cab increases less than in direct proportion to the mass and appears to reach a limiting value. Simulations of overturns on featureless terrain, such as a uniform slope, give the opposite result of energy increasing more rapidly and in direct proportion (Schwanghart, private communication). The linear dimensions of the tractor and cab increase roughly according to the cube root of the mass, and the height of fall of the centre of mass in a uniform slope overturn depends on the tractor size, so the potential energy increases approximately to the four-thirds power of the mass. For an overturn down a bank of fixed height, however, the height of fall varies less with mass and the roll angle at impact decreases as the track width increases. If a higher bank had been chosen for these simulations the limiting behaviour shown in Fig 5 would still have been present, but would have occurred at a higher energy and tractor mass.

The energy/mass relationship of 1.80 J/kg given by the linear regression in fig 5 is remarkably close to the value of 1.75 J/kg recommended by the EEC Study Group (Boyer *et al*, 1976) for the sideways energy in proposed static test procedures, partly on the basis of simulations of overturns on a uniform slope. Since the two types produce characteristics with opposing curves, their combination in a single linear function appears to be logical, and the choice of a mean line rather than a maximum is justified by the factor of safety inherent in the generous zone of clearance.

From this, and the general relationships noted above between sideways energy absorbed and roll and vertical impact velocities, it may be concluded that the criteria for sideways cab strength in present standards is adequate. The possibility has been demonstrated, however, of collapse in extreme accident circumstances of a cab which is only just capable of meeting present residual vertical strength requirements.

Fig 5 Energy absorbed in cab at maximum sideways deformation as a function of tractor mass for simulated overturns down a 2.25 m high bank



Acknowledgment

The work summarised was part of an extensive project involving contributions from many people, particularly in the production of experimental equipment, execution of the tests and analysis of results. The author is most grateful to them all.

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Mechanisation of forage conservation in the UK

R T Lewis

Introduction

FEW would disagree with the statement that forage crops, mostly grass, constitute one of our most important national farming enterprises if not the most important enterprise. There is no doubt that in Britain the total area occupied by intensive leys, permanent grassland and rough grazing far exceeds the national area devoted to any other major crop. The quality of our grass farming and the associated livestock industry was recently thought among the best in the world by mainland Chinese authorities when they were deciding who should advise them on the development of each section of their own agricultural industry.

Regardless of this kind of accolade much work rightly continues to be done to increase our efficiency in grass production, conservation and feeding. In conservation, the main subject of this article, many years of effort in research, machine development, and advisory work has brought about only a slow rate of change from haymaking to silage, in spite of our wretched summer weather. About seven million tonnes of hay, 56% of the conserved crop, is now made each year. The co-operative grass dryers which began to operate in the late 1940s did not make much head-way even in those days of cheap energy. Now the constraint on this process is painfully obvious and a few specialised grass drying companies handle at most 1% of the conserved crop.

In considering how to divide development effort between the two main conservation systems, hay and silage making, it is interesting to look at some comparisons of energy use in a recent paper (White, 1979). Calculations showed that 60-90% of the energy required for silage and field dried hay was accounted for by fertilizer use, and that silage required about 10% less energy than field dried hay to produce the same amount of metabolisable feed energy. For general efficiency we must continue to improve systems and machinery for producing both hay and silage, but White's analysis suggests that the main energy savings may come from the chemists, plant breeders and agronomists.

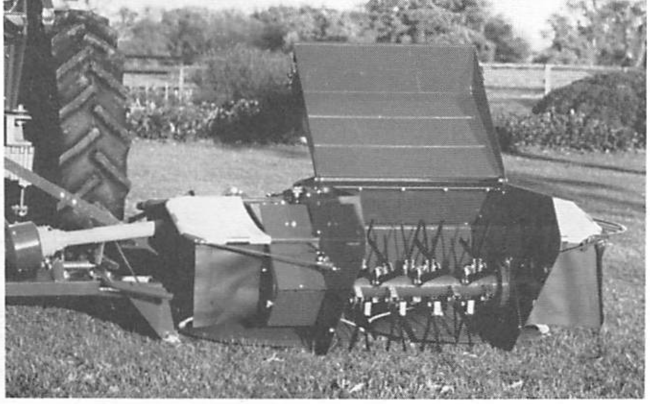
Cutting and conditioning the crop

Turning to machinery development, the first stage of conservation for both hay and silage involves cutting and probably conditioning the crop. For cutting, the introduction of rotary mowers nearly twenty years ago made possible a tremendous improvement in work rate and in the ability to cut high yielding leafy crops without blockage. Although these machines have a much higher power demand than cutter-bar mowers we shall not look back. Conditioning is a process adopted to increase the drying rate after cutting of thick tissues with heavy cuticle and make more rapid and even drying of the whole crop possible. Early attempts at conditioning were made with roller type crushing or crimping machines brought over from the United States, in the early 1960s. In the 1970s research and development work at the NIAE showed that passing the cut crop over a horizontal power driven axle equipped with Y shaped steel flails gave the most severe treatment where it was wanted, at the base of the crop, and minimised leaf damage. Current work by the NIAE team suggests that even better conditioning work may be done by a rotor equipped with polypropylene brushes instead of steel flails, with the added incentive of reducing the possibility of tramp metal getting into forage harvesters and causing mechanical damage, or going through the machine to be ingested later by cattle.

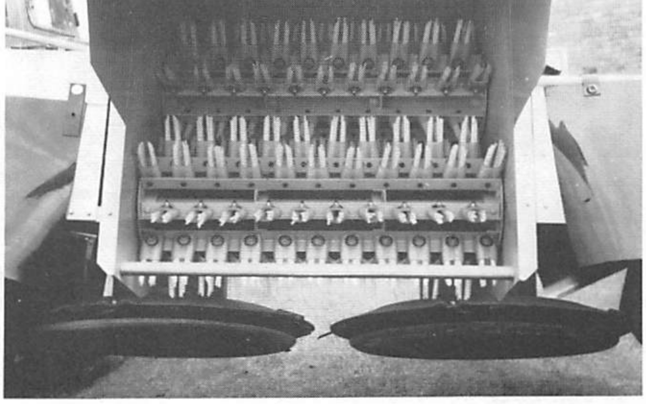
Mechanising haymaking operations

After cutting, hay and silage making systems differ. Most of our hay is field cured which initially involves spreading and turning the crop during the day then gathering it up before evening dewfall. In unsuitable weather these processes may have to be repeated for a number of days, with losses of metabolisable feed energy mounting through leaching, respiration, mechanical destruction of leaf and perhaps mould development. The modern generation of vertical axis machines with one or more rotors which spread or gather the crop do so thoroughly and with considerable speed. However, one cannot help feeling that the older type of over-or under-shot tedder, slow though they may have been, did a more satisfactory and gentler job.

The Massey Ferguson, MF 70 mower-conditioner with the NIAE designed steel spoke rotor (photo courtesy of MF)



NIAE experimental twin intermeshing brush conditioner fitted to a 2.1m drum mower (photo courtesy of NIAE).



Sperry New Holland take tedder model 254 (photo by courtesy of Sperry New Holland)

With the use of acid based silage additives a common and successful practice it is not surprising that much research has been done to develop systems for the application of similar organic acids to hay. Ammonium propanoate has been shown to be an effective fungicidal preservative, but the engineering problems of applying the correct quantity according to moisture content, and obtaining uniform application throughout a swath have still not been solved. When these problems have been overcome the haymaking process will be less weather dependent because it will be possible to bale hay at higher moisture contents after a shorter curing period and still store it successfully.

Conventional balers have changed very little in recent years, but still survive in the market in considerable numbers. Field to barn handling was successfully mechanised fifteen years ago by flat eight and more recently flat ten bale accumulators and matching tractor front loader grabs. The small bale was and still is the most convenient feeding package for the majority of farmers. But with farm sizes on the increase and labour numbers still decreasing the time was ripe for a surge in the sales of big balers in the mid 1970s. "Rectangular" and "round" big balers certainly increased the output per man, packaged and carted. Rectangular bales were put under cover as they were not expected to be weatherproof. Round bales on the other hand were usually left out and proved disappointingly susceptible to the penetration of rain. Furthermore the round big bale has so far resisted all attempts to dry it by ventilation whereas conventionally shaped bales, small or large, can be artifically dried in barns or tunnels. At about twice the price of a conventional baling and handling system, and with some unsolved disadvantages, big round balers have not substantially upset the conventional market.

Farmers wishing to bale with conventional machines but to handle the material in large packages can look at a number of possibilities. The simplest development is to use a standard flat accumulator and the matching grab loader to stack loose bales four or five high to cure in the field. Later a tractor or rough terrain fork lift mounted grab can be used very effectively to build large stacks at a short transport distance.

More expensive and sophisticated systems load single bales automatically on special trailers, either from the ground or directly from the baler. Bales may subsequently be discharged one by one for stacking, or off-loaded as a stack directly from the trailer. Alternatively a special "accumulator" towed behind the baler will form, tie and discharge packages of 20 bales for subsequent grab handling. The last three systems are more likely to appeal to contractors handling large tonnages than to farmers. Large scale stock farmers who contemplate introducing a rough terrain fork lift into their handling system should look at the opportunities for moving half tonne packages of hay in the field and in and out of store.

The recently introduced high density balers have the potential to increase the package density of straw which has to be transported long distances in economic lorry loads. They may not be so appropriate for our hay crop unless high bale density interacts favourably with preservative application.

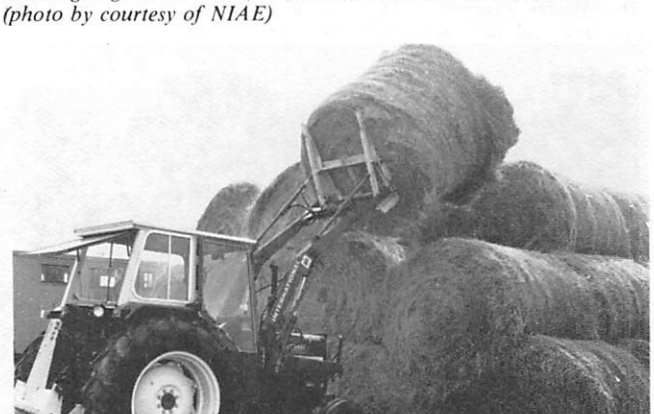
Mechanising silage making operations

In relative terms silage may be made as a "low" or a "high" dry matter product. The essential difference between the two lies in the amount of water lost by the crop during a controlled period of wilting between cutting and conditioning, then chopping and transporting. To make low dry matter silage the crop needs to be loaded into a storage structure at a dry matter content preferably between 25 and 30%. At lower dry matter levels a considerable amount of effluent will be produced, leading to feed energy losses and disposal problems. As grass/clover mixtures cut at a growth stage designed to give high "D" value feed have dry matters in the 15-20% range some wilting will usually be necessary even in a low dry matter silage making system. Also acid based additives will often be introduced at a controlled rate during the chopping process to lower the pH of the stored mass and ensure rapid establishment of the desirable anaerobic fermentation process. By contrast the dry matter content of grass intended for high dry matter silage has to be increased to 35-50% by wilting in the field before the chopping process is carried out. The two systems involve different combinations of machines and, particularly for the lowest and highest dry matter levels at loading, different types of storage structure and handling equipment. Whichever system a farmer uses, he can tool up to make the quantity of silage he needs to carry his stock through the winter.

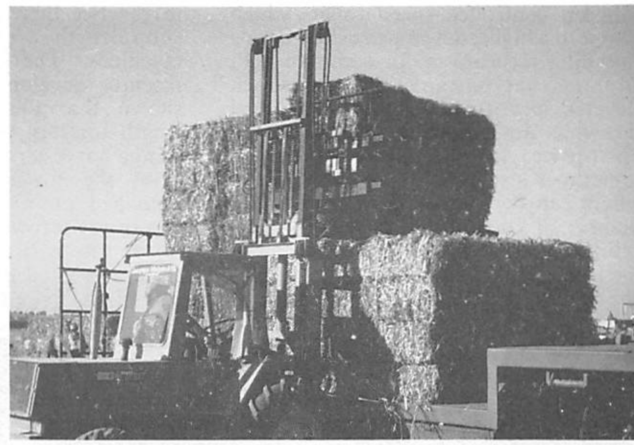
Low dry matter silage making is the simplest system to mechanise. The crop will be cut with a flail mower, or perhaps a mower/conditioner. After a short wilting period it can be picked up with a flail type forage harvester or a "double chop" machine with flails and a flywheel

Large round baler, American (Vermeer) type (photo by courtesy of NIAE)

Stacking large round bales (4m³), track front loader-prong-type handler (photo by courtesy of NIAE)



McConnel balepacker working in hemp at Chalons sur Marne (photo by courtesy of F W McConnel Ltd)



McConnel balepack gripper working in hemp at Chalons sur Marne (Photo courtesy of F W McConnel Ltd)

type knives-and-shear-plate mechanism which chops to a shorter length. In both cases the crop is discharged into a trailer suitably adapted for the job of separating the crop from a high speed air stream and transporting a reasonable weight of bulky material. Enough trailers must be available to transport crop to the storage site and keep the forage harvester in continuous operation. At the store the crop will be dumped on (preferably) a concrete pad, then loaded into a bunker or formed into a clamp using a tractor mounted buckrake. Each day the last operation should be to sheet over the crop with polythene to limit oxygen penetration into the mass, and thereby ensure as far as possible the rapid onset of anaerobic fermentation.

When the time comes to feed the silage, controlled self-feeding from clamps or bunkers involves the lowest handling cost, but perhaps the highest losses. The cattle may waste a considerable amount of feed, particularly if it was long chop material. Aerobic degradation at the feeding face is difficult to control. Small wonder that the farmer turnout at a recent ADAS demonstration in the Midlands of tractor operated silage cut/transport systems surprised the organisers.

What changes have we seen in recent years in the machines used for making low dry matter silage? The general increase in power available from tractors has increased machine output and the uniformity of the processed crop. Extra power is particularly helpful for the smaller scale operation where the tractor hauls both forage harvester and trailer. The anti-scalping rollers fitted to flail type forage harvesters have minimised the presence of soil in the crop, a problem in fields with uneven surfaces. Tapered body trailers have speeded up crop discharge at the store. Large capacity push-off type buckrakes have increased the rate of loading into the storage clamp or bunker. Little significant change has occurred in the design of double chop harvesters, but their numbers, together with those of metered chop harvesters, increased sharply in the second half of the 1970's indicating perhaps a change to a more efficient conservation system. The one notable introduction into low dry matter silage making has been the use by smaller scale stock farmers in the west and south-west of the continental forage wagon. This machine is a strengthened unbalanced trailer, carrying at the front a swath pick-up mechanism, delivering the crop into a full-width elevator/chopping device which feeds into the trailer body. A power driven discharge mechanism in the body completes the structure. The initial performance of these machines in wilted grass was often unsatisfactory, as they were designed primarily for hay. General improvements in terms of strength and a reduced chop length have made them more suitable for our conditions, and capable of high seasonal outputs as some contractors have shown.

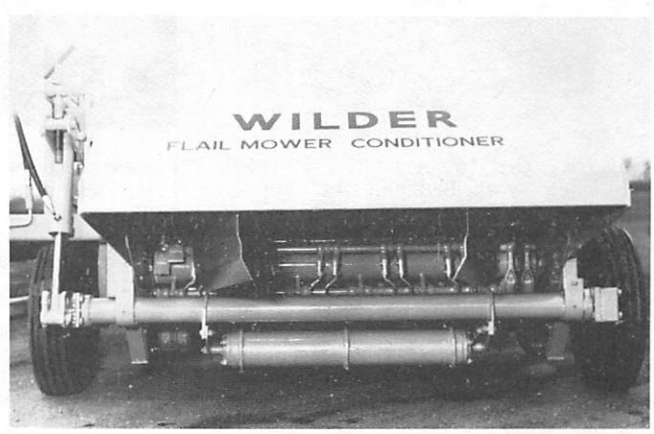
Systems for making high dry matter silage are usually used for large herds where high quality feed cuts down the total tonnage to be handled and fully mechanised feeding systems are necessary. The crop has to be cut and wilted to at least 35% dry matter, up to 50% for ensiling in towers. A wide choice of drum or disc type rotary mowers is available, with combined conditioning mechanisms from a number of manufacturers.

But a difficulty does arise for the manager who wants to pick up his crop at a precise dry matter level. The forage moisture meters which are available are not capable of giving quick and accurate results over such a large volume of material. Work at the NIAE on new devices to provide the necessary information should be complete very soon. Let us hope that a UK manufacturer will take up the designs and market an instrument with the minimum of delay.

When the crop reaches the planned dry matter level it is processed with a metered chop forage harvester. In this machine the wilted material is compressed

Farmhand hydraulic push-off buckrake loading silage into a clamp at a National Grassland Demonstration

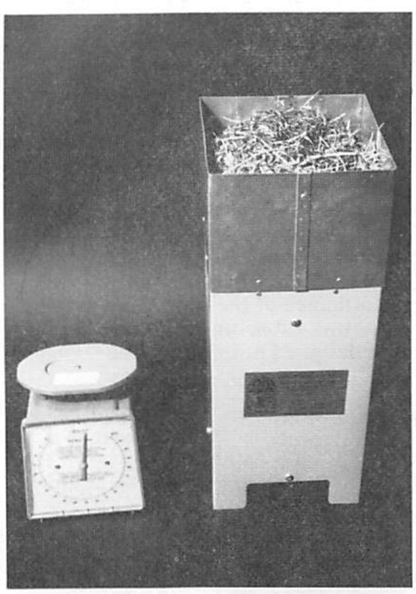
Anti-scalping roller on a Wilder Flail mower conditioner (photo by courtesy of John Wilder Engineering Ltd).



between controlled speed rollers which pass it to a highly developed cylinder type chopping mechanism. In common with all forage harvesters the material is then elevated into a trailer by the combined throwing and blowing effects of the chopping mechanism, although sometimes a separate fan is fitted. Chop length can be controlled by varying the number of knives fitted to the chopping cylinder and/or by varying the speed of the feed rollers. In theory the crop can be chopped to lengths as short as 6 mm but in practice there is a wide variation in chop length even with metered chop machines. The chop length analyser recently developed at the NIAE has shown that the lowest average chop length for this, the most precise of the forage harvesters, is about 25 mm.

At the tower the crop is usually unloaded into a dump box which feeds it to a rotary thrower for delivery to the top of the tower. If a top unloader is to be used it is good practice to use a rotary spreading device to push the crop evenly towards the tower walls. Bottom unloaders work better if the crop is dropped into the centre of the silo. When feeding begins the silage may be discharged into a forage box for distribution, or an automatically controlled conveying system can be installed.

Moisture meters — (above) Froment 1210; (below left) Wile 351 meter with hay extension; (below right) Tower Silo's Croptester Mk II (photos by courtesy of NIAE)



The forage harvester is the heart of this system, so a few technical comments are in order. First, the power requirement of the chopping process may double if the knives are allowed to get blunt, or the knife/shear plate clearance is not correct. In this context is it good that an efficient sharpening system is now built into each machine. Second, the entry of tramp metal into the chopping mechanism causes expensive damage and may stop work for a day or more at a very critical time for the silage quality point of view. Here we still lack a fully effective metal detection and feed declutching system; most manufacturers do not even bother to fit one. With the best will in the world it is difficult to prevent odd pieces of metal getting into the swath, so we need a scanning system which will detect the offending articles ahead of the harvester rather than in it.

When filling the silo we still frequently have a bottleneck at the thrower, which seems to need an enormous amount of power. Recent work suggests that the uneven flow of material into the thrower, often experienced from dump boxes, is partly to blame. But have we looked carefully enough at the blade design of the thrower itself?

When feeding out from the tower is in progress, difficult problems can still arise if the unloader breaks down. In most cases nowadays insufficient maintenance of the machinery will be the cause of the trouble, as designs have improved a great deal since we first began using forage towers.

Future development

There are a few areas where improved design, the introduction of new components in machines, or the development of new operations within systems may increase operating efficiency. In general, however, there is a wide choice of satisfactory machinery available to the forage conservationist. Most observers suggest that the main reasons for high system costs or low feeding quality material or both are to be found in poor system design and less than optimum operating efficiency. In other words, detailed attention must be given to all management aspects of the chosen system, from crop and machinery selection through cutting dates and rates of work to the type of silo and feeding method. Only when the right decisions are made and the whole system runs like clockwork will the best feed be made at the lowest cost.

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Correction

35/4, page 90, fig 2, caption should have read: Rolling jab planter further developed by Geest as part of the Groom System for local manufacture.

Maincrop potato production in Great Britain

O J H Statham

Summary

A REVIEW of current potato production techniques identifying trends and developments with particular emphasis on mechanisation.

Potato production in perspective

THE potato is unique amongst the major arable crops in that only 65% of the planted area is lifted by complete harvesters. This proportion has not increased since 1975 and must, at least in part, reflect for a significant proportion of growers unsatisfactory design and stagnation of ideas and developments. This fact clearly has implications for all the production stages of mechanical potato growing and it will be returned to later in the paper.

The UK is essentially self-sufficient in its potato requirements. Current per capita consumption is 98 kg/year of which just over 25% is now consumed in processed form (table 1), this country having the largest potato processing industry in Europe. Within broad limits potatoes are a price inelastic commodity and therefore with a high static consumption pattern, it is inevitable that grower numbers have declined as has the area planted (fig 1).

Clearly the concentration of production into fewer holdings, which has taken place over the last two decades has brought its pressures to mechanise in the face of labour shortages and the recognition of a need for greater timeliness. Nowhere has this been more evident than amongst those producers growing for the expanding processing industries. Whilst on the more favourable soil types, satisfactory systems are being developed by many growers; mechanisation of seed handling, planting, harvesting and grading has much potential for improvement.

Seed storage and handling

In Great Britain as a whole currently around 30% of all seed is traditionally sprouted and less than 10% minisprouted. In the past great confusion has surrounded the practice of chitting, the methods to be followed, the necessity or otherwise of avoiding damage to sprouts during planting, the growth which will be produced, etc, etc. The concept of physiological age in seed has led to a much better understanding of plant growth patterns. Increased physiological age, the direct effect of sprouting, will result in earlier plant emergence and earlier tuber initiation but also earlier haulm senescence. Taken with the characteristic of apical dominance the result will be increased yields at early harvests. However, as a consequence of earlier senescence yield may be reduced if harvest is late. The manipulation of physiological age to produce the desired crop growth patterns requires detailed programming on a variety basis and access to relatively sophisticated temperature controlled seed storage. For the early grower it will continue to demand the use of traditional chitting methods and seed handling and planting systems which avoid damage to an apically dominant sprout. For the maincrop grower less demanding requirements may suffice eg. minichitting, which in turn may allow bulk seed handling, storage methods, and planting mechanisms leading to a level of chit damage which is acceptable. The introduction of belt feed high speed planters highlighted the problems and logistics of handling particularly trayed seed onto the field and into the planter. Typically 60% of the planters time could be spent out of work either turning or replenishing its hoppers. A larger unit load than the ⅓ cwt. tray is required if the process is to be speeded but as yet few wholly bulk systems are to be found on farms, although many growers are experimenting with the use of larger containers such a ½ ton and 1 ton pallet boxes.

Cultivations and planting

Ploughing is almost universally employed to break ground for potatoes after previous crops but the interesting development in recent years has been the widespread adoption of power driven cultivation equipment for final seed bed preparation. Power harrows are proving more popular than rotary cultivators and have been shown in Scottish Institute of Agricultural Engineering trials to have better clod comminution and to be more energy efficient.

Table 1 Estimated tonnage of raw potatoes used for processing in Great Britain

Product		*1974/75*	*1975/76*	*1976/77*	*1977/78*	*1978/79*
		June/May seasons – Thousand tonnes				
Canned whole	Home-grown	27	18	26	14	8
	Imported*	(4)	(3)	(2)	(1)	(1)
Crisped	Home-grown	450	342	275	358	444
	Imported*	(10)	(54)	(122)	(42)	(27)
Dehydrated	Home-grown	149	147	101	88	167
	Imported*	–	(60)	(55)	(10)	–
Frozen or chilled	Home-grown	364	327	266	362	571
	Imported*	–	(78)	(77)	(15)	–
Total home-grown usage		**990**	**834**	**668**	**822**	**1190**
Total Human consumption G B crop		5210	3670	3380	4420	4847
Percentage home crop processed		**19.0%**	**22.7%**	**19.8%**	**18.6%**	**24.6%**
Total Processed in Great Britain		1004	1029	924	890	1218

** Figures in brackets are the imports of raw potatoes used for processing in Great Britain.*
The following ratios are used to convert raw potato to processed product:– Canned 10 : 9 (can content including brine) Crisps 4 : 1 Dehydrated 7 : 1 Frozen 20 : 9

O J H Statham is Machinery Officer at the Potato Marketing Board.

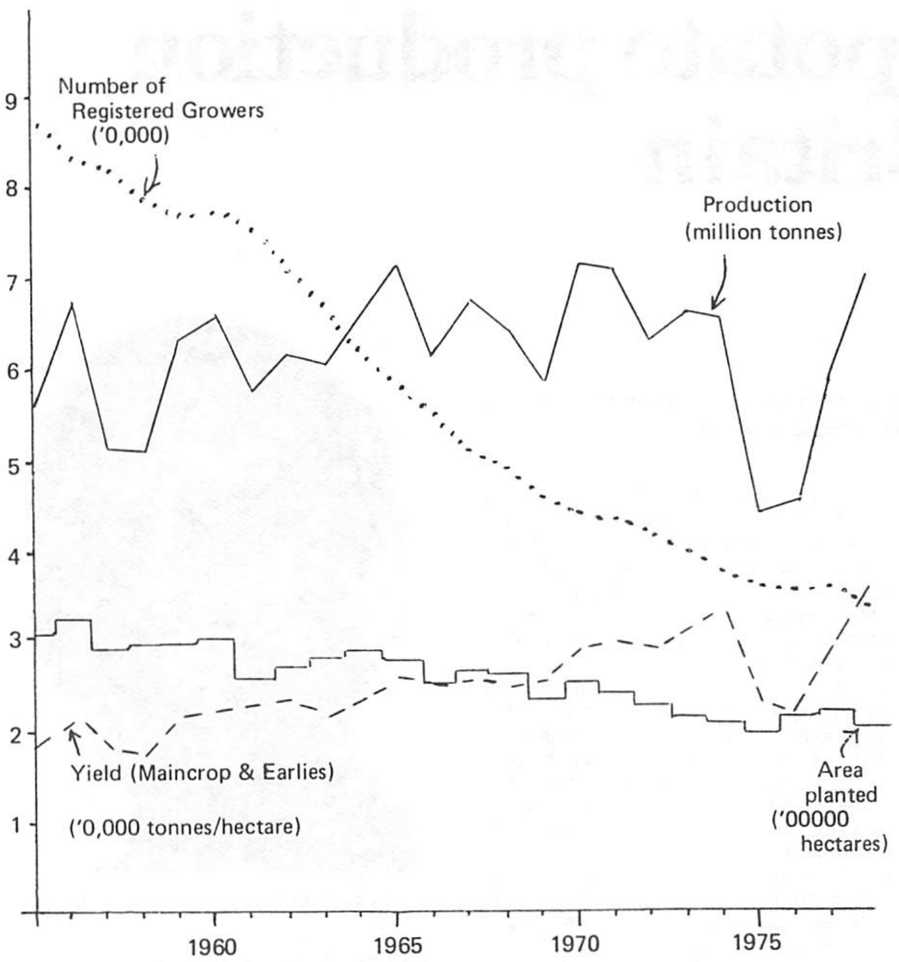

Fig 1 Trends in plantings, production and grower numbers in Great Britain

The most important development for many growers however has been the introduction of stone windrowing and burying machinery. Arguably a technique which will have a greater impact on mechanised potato harvesting than anything else; stone and clod windrowing will ensure that hitherto marginal land will remain in potato production whilst at the same time accelerating the trend towards two row unmanned harvesting systems. Where stones are a significant problem at harvesting both from the point of view of separation from the crop and damage, they may be dealt with if at all either by stone picking and removal, by stone crushing or by windrowing. Of the three systems windrowing has gained rapid acceptance in the last five years and a number of systems have evolved. For the most part the equipment is based on a two row configuration where separated clod and stone is buried forward of the windrower. In practice deeply cultivated land is ridged into two row beds which are subsequently lifted by the windrower. Stone and if it occurs clod is separated out on a digging web to be conveyed forward over the next bed to be treated and deposited in the loosened furrow bottom between beds. As it progresses across the field the windrower will compress the stone into these valley bottoms. Planting takes place into essentially a stone and clod free soil medium with obvious advantages for the subsequent harvesting operation. Stone windrowing is an exclusively British development with tremendous potential.

Latest of the current generation of stone windrowers placing its stone forward over a two-row bed

Currently two manufacturers are offering modified windrowers with planters mounted on them but it is more usual for two row planters to be used in a separate operation. Whilst in use numbers of belt fed and cup fed planters are roughly equal, sales of cup fed planters are now predominating. There is some interest in 4-row models as a means of increasing output although draft problems can cause difficulties and there is often an unhappy relationship with windrowers especially where asymetric row spacings are used to accommodate the windrowed material. There has been a decline in the number of growers placing fertiliser with the planter and an attendant increase in the amount of fertiliser broadcast prior to planting. Whilst fertiliser is mostly applied just before planting, surveys show that autumn applications are practised only by the large scale growers suggesting that management pressures to speed planting rates are a major consideration.

The control of weeds, pests and disease in the growing crop is now largely effected by the use of chemical sprays, apart from a small amount of weed control carried out by cultivations and the hand rogueing of plants in seed crops. Trafficing in the crop is now with the sprayer rather than with inter-row cultivation equipment. If a ridge is to be built which will endure for the full season its profile needs to be somewhat different from the ridge which is pulled down and rebuilt several times. The move to wider rows and even asymmetric rows can be very beneficial in obtaining the quantity of tilth required without having to work ground too deeply. It can be seen from table 2 that 75 cm rows still predominate but it will not be long before 90 cm rows represent the standard. This is a very welcome move for it is becoming obvious that tractor tyres are causing appreciable damage to the ridge flanks resulting in increased clod formation and in some cases damage to the tubers.

Harvesting

In England and Wales 50% of the crop is lifted with single row manned trailed harvesters. With a seasonal average of under one hectare per day the level of output is insufficient for the larger

Table 2 Proportion of crop planted at different row widths

Row Width	*South West*	*South East*	*West Midlands*	*East Midlands*	*East Anglia*	*Yorks & North*	*Scotland*	*Great Britain*
	%	%	%	%	%	%	%	%
up to 26 in (65cm)	3	1	1	–	–	–	1	1
up to 28 in (70cm)	38	16	31	17	6	21	32	21
up to 30 in (75cm)	39	33	54	61	66	64	60	57
up to 32 in (80cm)	8	14	1	6	6	9	2	6
up to 34 in (85cm)	5	4	3	1	1	1	1	2
up to 36 in (90cm)	7	32	10	15	21	5	4	13

Table 3 Crop area harvested by different types of harvesters

		England and Wales		*Scotland*	
		Hectares '000	*%*	*Hectares '000*	*%*
Spinner		8.9	7	1.7	6
Digger	1 row	8.8	7	2.5	8
"	2 row	18.2	14	14.1	47
Trailed manned					
	1 row	63.1	50	6.7	23
	2 row	9.7	8	3.2	11
unmanned					
	1 row	1.1	1	–	–
	2 row	10.6	8	.1	...
X-ray		4.0	3	.7	2
Self-propelled		2.1	2	.6	2
		126.6	**100**	**29.7**	**100**

grower. Although the proportion of the crop lifted by two row unmanned machines is still quite modest (table 3) it is estimated that nearly 50% of all new machine sales fall into this category. With a potential output in excess of three hectares per day the work rate is more realistic by modern farming standards. The problems of separating tubers from residual clod and stone are often best dealt with by static machinery at the store. X-rays which are currently the most efficient separation methods, work better on static machines where the whole operating environment can be so much better. Two row unmanned harvesters which used to be confined to the soils of the fens and a few other favoured areas have expanded rapidly into most growing areas of this country, a process accelerated by the successful development of stone and clod windrowing systems. Most of the principal manufacturers have introduced self-propelled harvesters at some stage, none however can claim any degree of commercial success for these models. It is not easy to see why this should be in view of some of the obvious advantages possessed by these machines, such as better traction and greater operator visibility and control.

Undoubtedly the greatest problem facing the potato industry is that of mechanical damage to the tubers — a problem which despite increased awareness is not diminishing to any appreciable extent. Machines of course are primary contributors and whilst damage is cumulative throughout the whole harvesting and handling system, harvesters do tend to be the biggest single contributor. One manufacturer has produced a machine which could fairly be said to have the potential for the lowest level of damage, however the harvester is labour intensive and slow and growers' reactions have so far not been encouraging. In the crunch situation of maincrop harvesting with perhaps twenty usable days in late September and October output is all important and ultimately all is sacrificed for it.

Handling and storage

Some attempts have been made to develop specialised transport systems for the crop, usually with the objective of reducing damage, but for the most part conventional farm trailers predominate albeit they are getting bigger and bigger. Mention has already been made of more sophisticated store cleaning and grading arrangements on the farms with higher output systems. Such machinery will frequently include variable speed dump boxes into which the trailers will empty. From the dump box the crop will pass over precleaners, haulm extractors and perhaps through specialised clod and stone extraction equipment before being inspected and loaded into store.

In recent years there has been something of an explosion in the construction of purpose built potato stores. Around 3½ million tonnes of potatoes are stored annually in this country and currently less than 25% of that tonnage has the benefit of even forced ventilation facilities. There is therefore considerable scope for the construction of environmentally controlled stores which will be suitable for the long term preservation of potatoes in first class condition. For the larger grower purpose built structures are essential if they are to cope with the logistics of handling greater and greater tonnages with fewer staff resources. Considerable development is taking place in the design and construction of stores particularly in the use of composite or sandwich wall panel systems. Insulation performance is of crucial importance in these long term cool stores and composites offer the attraction of making the insulation material contribute to the structural strength of the panel whilst being mechanically protected and not subject to vapour transmission and deterioration through interstitial condensation.

The best environmental control systems all employ ambient and recirculated air mixing systems allowing very close control of temperatures and temperature gradients within the overall constraint of the availability of air at a

Self-propelled harvesters have yet to achieve any significant market penetration

low enough temperature. Generally speaking a store temperature of 5° C can be maintained until the end of April or early May. Whilst pallet box storage is increasing in Scotland where there is in any case a lower usage of harvesters, it is declining in England and Wales because it presents a constriction in high output systems. Particularly for the larger co-operatives and central grading stations bulk and box stores of up to 10,000 tonnes are now being built. This trend is likely to accelerate in the next few years as more of the crop grading and market preparation is undertaken in these establishments.

Grading and marketing

In general terms electronics have not so far been widely used in agriculture. However the adoption of electronic sizing and grading by sectors of the potato industry has placed the crop firmly in the forefront of this new technology. The market possibilities, particularly for electronically sized potatoes, are considerable and much work is now being done to develop automatic quality selection machinery. For the most part, however, developments have taken place in weighing and packaging equipment and fully automated systems now exist to pack potatoes in containers weighing from 1 kg to 25 kg.

The opening paragraphs of this review drew attention to the unique position of the potato crop viz a viz mechanised harvesting. The penultimate paragraph highlighted the use at the same time of some of the most modern and sophisticated technology available in agriculture. The contrast demonstrates the continuing role which agricultural engineers at all levels and in all disciplines have to play in the production, harvesting and marketing of the potato.

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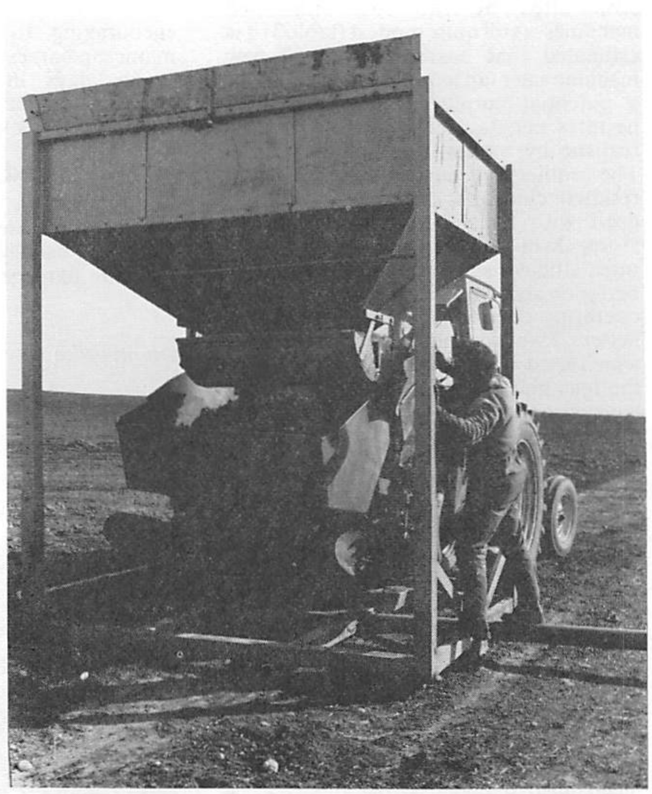

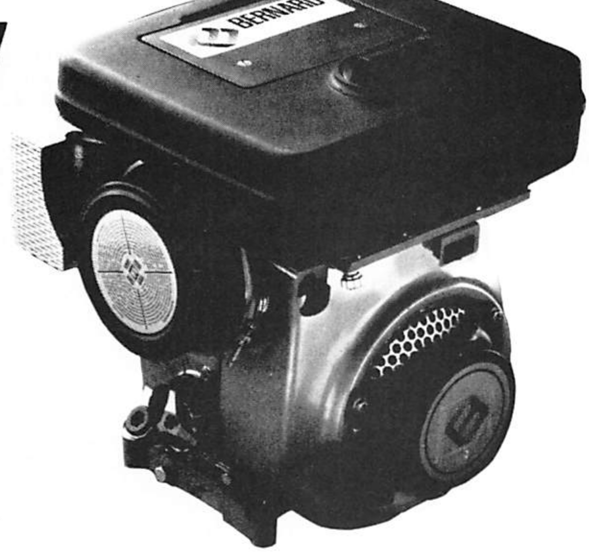
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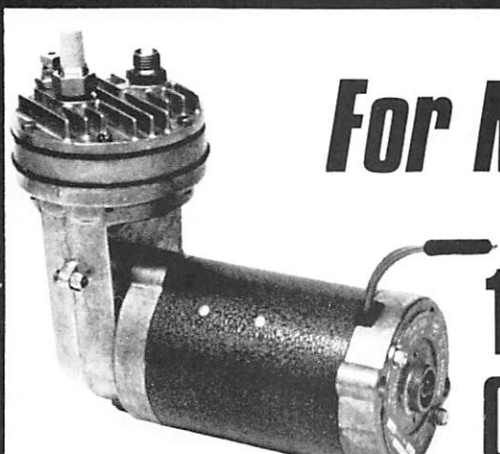

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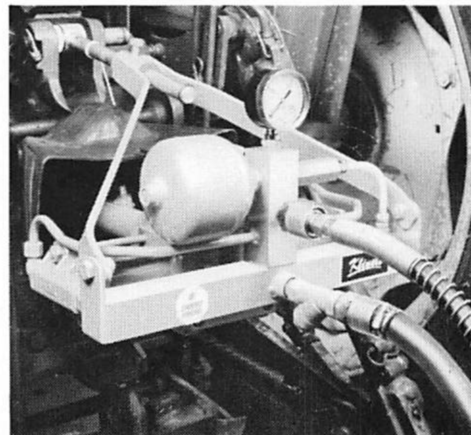

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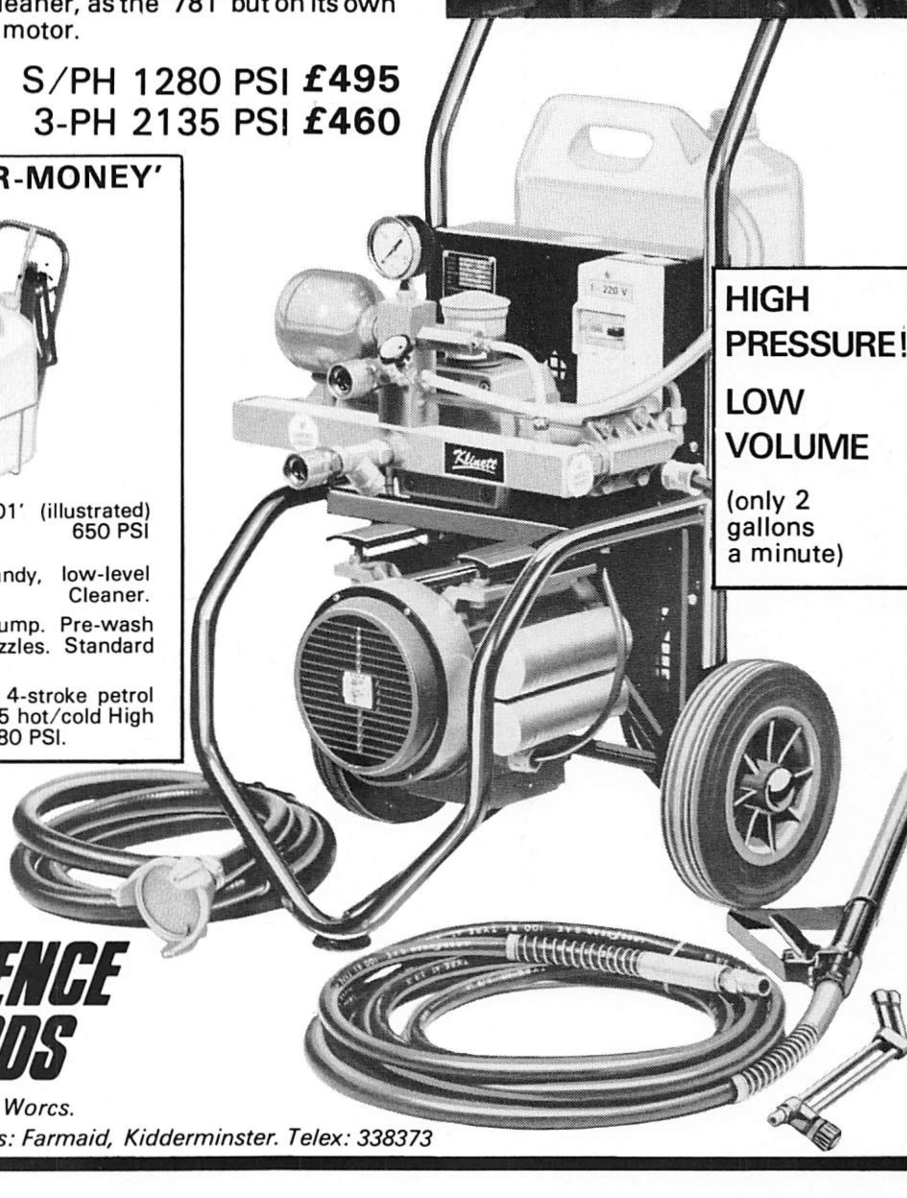

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