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Advances in machine technology

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Front cover:
Floating beam mole plough designed at Silsoe College *(see page 67)*

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Guest editorial

Advances in machine technology

R J Godwin

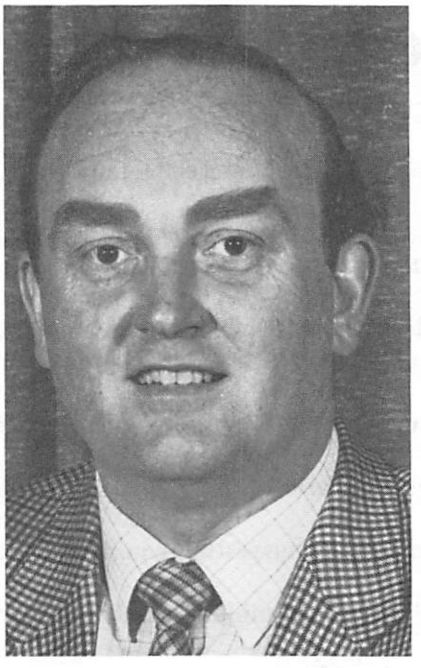
THE recent success of agriculture in reaching and exceeding production targets has resulted in considerable pressure for change within agriculture and the industries that support it. These changes arise from:

1. The need to reduce input costs to maintain profit margins as commodity prices fall in real terms.
2. Increasing public concern over environmental and safety issues.
3. The need to improve the quality of food in competitive world markets.
4. The need to avoid surpluses by diversifying into the production of alternative crops for food, animal feed and fibre commodities.

These in turn create a demand for a greater rate of technological advancement, assisted by the advancement of technology in other industries which have applications in agriculture and food production, eg materials, sensors and microprocessor developments.

Change is made more difficult at the current time by a lack of funding for fundamental and applied research and development from both public and private sources. Although painful in the short term this restriction in funding may have long term benefits providing that imaginative packages can be developed where public funds, from the research councils and MAFF, are linked to funds from the primary producer and support in terms of cash and kind from the manufacturing industry. The final output should therefore be far more cost effective research and development that exactly meets the machinery needs of the farmer, and so enhance the marketability of the equipment.

Professor Dick Godwin holds the chair of Agricultural Machine Technology at Silsoe College, Cranfield Institute of Technology, and is Chairman of the Dept of Agricultural Engineering. He was Convenor of the 1987 Convention.



Despite the funding problems at this time of change, the technological thrust continues in industry, research institutes and universities as demonstrated by the following papers. These have been selected to represent the key advances in areas of crop and animal production. The development in the understanding of the basic principles of soil and crop handling continues and allows new techniques to be developed to:

(i) minimise energy outputs,
(ii) reduce operating time,
(iii) delete redundant operations,

which will reduce input crops and give rise to new machines for soil and crop management. These practices in turn require adaptation of the tractor which, due to investment considerations, will be evolutionary rather than revolutionary. The changes in tractor configuration will be forthcoming, aided by improvements in sensor and control technology.

The reduction in input costs of chemicals in the form of sprays is paramount in ensuring that the agrochemical industry can supply agriculture at costs acceptable to all parties. This can be achieved by ensuring that the spray reaches the target with minimum wastage and sufficient precision. The techniques described are leading to an improved generation of machines that not only meet the above requirements but minimise environmental pollution and reduce the risk of operator contamination.

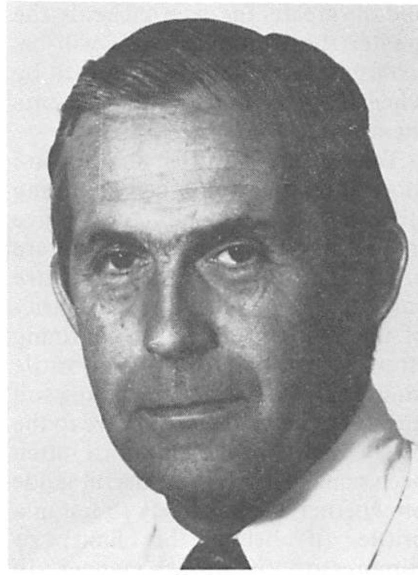
The papers give examples where the interface between biological materials is linked through appropriate sensors to machines, via improved control systems. This is possible with the greater use of microprocessor based systems which allow the machines to be managed at the current optima for production. These systems can be readily modified as requirements change and demonstrate the determination of the industry to advance the technology in support of the farmer and ultimately the consumer.

Developments in machinery and techniques for improved soil and water management

G Spoor

Summary

IN areas where machine development and evolution has continued for centuries, it becomes increasingly difficult to introduce new machines and systems. Developments are usually combinations of old and new ideas to satisfy current needs. This has been the pattern in the soil and water management area. An appreciation is made of the value of the critical state concept within soil physics as well as descriptions of new tillage systems, new implements and developments in drainage. Traffic management and changes to running gear are discussed with reference to preventing soil structural damage from excessive soil loadings.



1 Introduction

Soil management practices have to satisfy the needs of mechanisation and soil and water conservation, as well as those of the crop itself, hence conflicts may arise. Crops will perform most satisfactorily in well structured soil, appropriately packed to maximise water availability and root and organism activity, with good drainage to avoid aeration stress. These conditions also satisfy many soil and water conservation requirements but there may be additional needs such as greater soil surface protection, which can upset early crop development and mechanisation. Efficient mechanisation operations require good support and traction, both of which can best be provided by a compact, mechanically strong soil, a state not always satisfactory for the crop.

Traditionally soils have been managed to provide the best compromise condition taking all requirements into account and, until recently, this approach has been largely successful. In recent years, however, some changes in approach have become necessary, due to the large increases in equipment weight and timeliness pressures, with their potential for increasing soil compaction and soil structural damage. This has made it increasingly difficult and often impossible to produce one soil condition acceptable to both the crop and mechanisation, with the result that either one or both have suffered.

Alongside the changes in the field, new scientific and engineering information has become increasingly available concerning crop requirements and soil behaviour when loaded with different types of equipment under different conditions. In most cases this information is still incomplete and hence taken alone, it cannot provide exact specifications for requirements. It has however, provided better understanding of the reasons behind the success or failure of many practices and developments. This, together with inventive skills and ideas, has enabled changes in machine designs and practices to be made, to improve the resulting soil conditions and the efficiency of certain operations.

Recent developments in soil and water management machinery and techniques in the areas of tillage, drainage and field machinery management will now be discussed. Consideration will be given to their performance and to the contribution of recent advances in soil and soil/implement mechanics.

Gordon Spoor is Professor of Applied Soil Physics in the Department of Agricultural Engineering of Silsoe College, Cranfield Institute of Technology, Silsoe, Bedford.

2 Soil physics/mechanics developments

One of the most important recent developments in soil mechanics is the increasing appreciation of the value of the critical state concept in understanding soil deformation behaviour. This has been greatly assisted by the fundamental work carried out in the University of Newcastle upon Tyne by Hettiaratchi and O'Callaghan (1980). Its particular value is not in quantifying the effects, but rather in helping explain soil behaviour in different loading situations and in identifying future approaches to improve the efficiency of operations. This concept helps clear misunderstandings on how soils are deformed and failed and identifies the three failure possibilities, which are:

a) tensile — failure along numerous planes, causing a decrease in density;

b) brittle — failure along a few well defined planes as a result of compressive loading, with a resulting decrease in overall density;

c) compressive — failure along many planes producing an increase in density.

The major controllable factor influencing the type of failure likely to occur in any given situation is the magnitude of the confining stress on the unit of soil to be deformed. The confining stress is the resistance applied by the surrounding soil to the deforming soil mass and it may be supplemented by other externally applied loads. The higher the shear strength of the surrounding soil and hence its resistance to movement, and the greater the external loads, the greater the confining stress will be. External loads can be applied by wheels or by the implements themselves.

Tensile and brittle failures are most likely to occur when confining stresses are low, and compressive failure when confining stresses are high. The higher the moisture content and/or the lower the density of the soil, the lower the confining stress needed before tensile or brittle failure can occur. The prevailing soil moisture content level, relative to the plastic limit, has in the past often been considered to be a useful guide on whether a soil is likely to fail in a brittle (if below the limit) or compressive (if above) manner. In the light of current knowledge, this guide is extremely restrictive and unhelpful. Experiments by Spoor and Godwin (1979) have shown that brittle or loosening failure is very feasible at moisture contents well above the plastic limit, providing confining stresses are kept low. Equally, compressive failure can occur well below the limit if confining stresses are high.

The essential requirement in all cultivation operations is to manipulate the confining stress level, to ensure the desired type of soil failure occurs. This can be achieved by means such as:

a) waiting for the surrounding soil condition to change naturally through wetting or drying,
b) changing the surrounding soil condition positively through cultivation, eg loosening or compaction,
c) varying the external load by modifying implement geometry or operation, and surcharging loads.

The nature of soil disturbance caused by wide and narrow cultivation tines, well documented for some time, has been supplemented in recent years by information on the disturbance caused with very narrow tines by Godwin and Spoor (1977) and by Spoor and Fry (1983a) and subsurface working blades by Albuquerque and Hettiaratchi (1980). Of particular value from this work for field tillage is the concept of a critical working depth, above which the brittle failure occurs and below which the disturbance is compressive. This change in the nature of failure with working depth is directly explainable using the critical state concept, which also identifies how critical depth position can be changed in any given situation.

Although by no means new information, knowledge of the drying pattern in soil when drying occurs through both surface evaporation and subsurface drainage and its importance for Spring seedbeds is becoming more widely appreciated. The moisture distribution after a good drying period is ideal for rapid seed germination and emergence, namely, a dry surface layer, moist conditions at seed depth and wet soil below to provide water for later growth. Moisture problems only arise if the soil needs to be disturbed before drilling. The need therefore, for a soil to overwinter with a level surface requiring a minimum of Spring disturbance, is paramount for timely rapid establishment as shown by Spoor and Godwin (1984).

Old lessons on Autumn seedbed preparation without the assistance of weathering on the heavier soils, have also been re-learned. Particular attention is now being paid to preparing a seedbed tilth before moisture loss under drier soil conditions, and to avoid excessive drying before reducing clod size on wet soils.

3 Tillage developments

Recent tillage developments for improved soil management will be discussed in two sections. The first, where weathering action has been significant, largely Spring operations, and the second where weathering effects are minimal, common in autumn.

3.1 Spring operations

A major change in approach to seedbed preparation, reflected in implement designs, is the greater emphasis being placed on control over working depth. Strict depth control at this time helps minimise both moisture loss and the risk of wet unweathered soil being brought to the surface, both being detrimental to seedbed condition. Improved depth control is being achieved on a wide range of implements by supporting them on a variety of crumbler or coil type rolls as well as on backward sloping blades. These devices also improve the clod breaking qualities of the operations. The Kongskilde Germinator harrow in particular has been developed for very precise depth control in line with the results of Swedish seedbed work by Hakansson and Polgar (1979). Deeper working spring operations with tines are now largely confined in attempting to eradicate tractor wheeling effects, rather than, as in the past, to encourage soil drying. On the lighter soils, where weathering action is much less important, the adoption of practices such as combined spring ploughing and pressing followed by direct drilling is increasing, particularly in the sugar beet crop. This technically not only minimises energy inputs but also conserves water, avoids tractor wheelings and provides protection against wind erosion.

The problems of breaking the wetter clods at depth, common during potato seedbed preparation, are being overcome using techniques and equipment which keep confining stresses to a minimum and allow brittle and tensile failures. Power harrows, rotating about either horizontal or vertical axes, offer this facility and are now in common use. The lifting and soil agitation action on elevator web machines such as stone separators and clod reducers helps produce the same result, particularly with the more weathered clods. Autumn ridging to increase the extent of clod weathering prior to these operations is also being considered.

3.2 Autumn operations

The design of equipment for alleviating deeper soil compaction problems has changed considerably over the past 10 years from the earlier use of essentially independent acting narrow tines to wing or sweep type tools, often in combinations at different working depths. Wider knowledge of critical depths has helped reduce the extent of ineffective excessively deep working. Winged tine and Paraplow type tools fail the soil in tension as it flows over them, minimising specific resistance and allowing soil fissuring to be achieved over the widest range of moisture conditions. The progressive type tools, whose leading shallower tines reduce confining stresses prior to disturbance by the deeper tines, allow considerably deeper working at higher moisture contents. Specific resistances are also lower as shown by Spoor and Godwin (1978).

Current interest lies in the identification of the need for these deeper operations, their positioning relative to other operations and subsequent management of the loosened soil. Recent trial results reported in Marks and Soane (1987) show that, unless a readily identifiable compaction problem exists, benefits from loosening are likely to be nil. In addition, significant traffic after loosening will reduce, if not eliminate, benefits, particularly if conditions are moist (Soane *et al* 1986). Although by no means common practice, some farmers are leaving deep loosening operations until last, either just before of just after drilling, and having considerable success. By controlling wing lift height or working depth, appropriate fissuring at depth is being achieved without adverse surface disturbance. The absence of traffic following loosening enables the crop to fully exploit the loosened condition. The increased use of subsoiler tines fitted below plough mouldboards is also an efficient pan bursting technique. The mouldboard removes the confining stress from the subsoiling tine and the undisturbed ploughed surface reduces the risk of recompaction from subsequent traffic.

Restrictions on straw burning have produced changes in autumn operations, the major change being the re-introduction or extended use of the plough, with a re-dedication to the use of skims. The use of twisted tines (Glencoe type), heavier disc harrows and combined power tiller/seeder arrangements has also increased in this straw handling context.

A further development accompanying the increased market interest in the plough is the successful re-introduction of the furrow press in various forms. Presses with large included angles on the segments are being used for compaction on the lighter soils and those with smaller angles for clod breaking in heavier soil situations. Pressing saves at least one further operation, helps conserve moisture under drying conditions and attacks clods at their weakest, before they have time to age harden following disturbance.

The clod problem following ploughing under extremes of moisture content on heavy soils has yet to be resolved. The most successful current seedbed preparation techniques in these situations, providing straw can be burned or removed, are still based on the use of tines or discs working from the surface downwards to minimise the clod problem.

Although new tine implement concepts such as the Dyna-drive by Watts and Patterson (1984), have been successfully introduced, most recent developments in the non-power driven tool category, have been combination tools linking well proven components. Tine and disc combinations are common, the tines aiding disc penetration under dry conditions and removing disc smear under wet. The discs in turn control tine working depth, thus preventing excessive penetration.

As in Spring, power harrows offer many advantages for breaking clods in loosened soil, either ploughed or surface cultivated, under moist or wet conditions, without the risk of creating pans or smeared layers. They are used extensively in this role in the wetter areas.

The achievement of level ploughing on the heavier soils, as a preparation for Spring sown crops, is sometimes a problem at the soil moisture extremes. Presses do not help greatly and there is a need for a levelling operation after some weathering. This is sometimes achieved by working on weakly frozen ground during the Winter period.

4 Drainage developments

Whilst there have been few major changes in drainage practice in recent years, machinery developments have continued in relation to pipe installation, gravel handling and mole drainage. The major change in drainage practice has been the significant move towards draining under drier soil moisture conditions, including draining through standing crops. This encourages the development of more permeable, stable structured soil conditions around the pipe, which are essential for efficient drain performance. Through-crop drainage has been accompanied by the development of forward discharging gravel trailers. These trailers follow in the same tracks as the pipelayer, thus minimising crop damage.

4.1 Pipe installation

The use of permeable backfill on the heavier soils in the United Kingdom has continued to increase, an item which can constitute up to 60% of the total drainage cost. This has stimulated modifications on the installation equipment to minimise the quantity required. Chain trenchers have been modified to cut much narrower trenches, almost matching trenchless equipment, and gravel "savers" have been introduced which allow the placement of narrow bands of permeable backfill in wide trenches.

Output of both trenching and trenchless pipe laying equipment has increased steadily, potential trenching speeds are now up to approximately 2-2.5 km/h and trenchless speeds are 3-4 km/h. Satisfactory installations can be made at the higher speeds with the aid of laser controlled grading equipment, providing ground surfaces are fairly smooth. In the presence of significant local surface undulations, however, trenchless speeds must be reduced to maintain grade. The trenchless tine is incapable of responding fast enough to compensate for the attitude changes of the power unit, as it passes at speed over undulations. A further unresolved problem with the trenchless tine, is the loss of grade through rapid tine shrinkage when moving into an area of low bearing capacity.

Gravel trailers have been developed to match the higher pipe installation rates. Together with increasing capacity and speed, manufacturers have taken the opportunity to minimise soil compaction damage through the appropriate selection of ground drive equipment and tyres.

Questions were raised in Europe some eight to ten years ago about the efficiency of drainage systems installed using the trenchless technique. Conflicting and variable results had been obtained in field experiments, with Naarding (1979) and Olesen (1979) reporting poorer drainage performance and higher water tables after trenchless installation whilst Eggelsman (1979) observed the opposite. These differences in performance were attributed to different soil conditions near the pipe but the causes were not identified. The causes were clarified when Spoor and Fry (1983a) examined their performance in terms of their working depth relative to tine critical depth.

Any soil compaction or smear beneath or to the side of pipe drains can significantly increase water entry resistance and reduce drainage efficiency in groundwater control situations as shown by Fry and Spoor (1983). Soil compaction alongside the pipe is unlikely to occur with trenchless tines working above critical depth, but it may develop in some instances when critical depth is exceeded. Trenchless machines can, therefore, be used with confidence in all situations if working depth is above critical depth. Subsequent drainage performance is likely to be impaired however in groundwater control situations if operated below critical depth on susceptible soils. Weakly structured, fine textured soils containing discrete macropores are the most susceptible, particularly if drained at high moisture contents. Operating below critical depth in perched water table or mole drainage situations is unlikely to cause problems, since the major component of water flow into the pipe is vertically through the backfill, rather than horizontally from the side. The use of shallower leading tines to relieve confining stresses ahead of pipe installation, allows above-critical-depth disturbance over a wider range of soil conditions and working depths, but as yet this modification has not yet been taken up commercially.

Although in existence for many years, the vee shaped delta trenchless machine has only become commercially successful during the past 3 years. The soil disturbance with this machine is always similar to an above-critical-depth failure and so installation problems are unlikely to occur on the susceptible soils in groundwater problem areas. In addition, soil cutting blades mounted at the rear remove any smear or compaction which may occur alongside the pipe, thus minimising the risk of water inflow problems. Similar soil cutting blades attached to the rear of the tile box on the vertical leg trenchless machine have been shown by Spoor and Fry (1983b) to offer equivalent benefits. The vee shaped delta machine causes considerably less soil disturbance than the vertical leg ploughs and hence offers advantages in grassland. To date, however, it has not been developed to install permeable backfill.

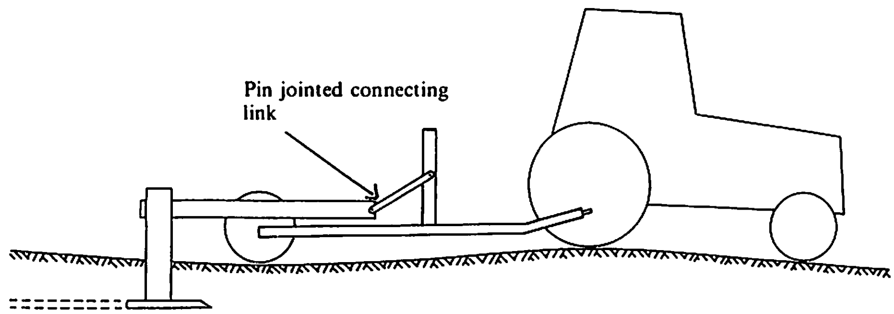


Fig 1 Schematic of floating beam mole plough and smoother frame with rear axle hitch

4.2 Mole drainage

Mole drainage has always been a relatively high draught operation and the common grading system, based on a long scrubbing beam, has a number of limitations. These limitations include the extent to which it can even out local surface irregularities, sudden grade changes when sliding over rises, an inability to install moles on a grade differing from the average field slope and blockage problems in heavy surface trash. Recent developments have successfully reduced the magnitude of these problems.

Mole plough draught is a function not only of the forces on the foot, leg and expander required to create the channel and leg fissures, but also of certain unnecessary parasitic forces. The parasitic forces come from the sliding resistance between the beam and the ground surface and the increased draught on the foot, caused by beam surcharge or confining stress. These parasitic forces, can, depending on mole plough setting, constitute up to 45% of the total force (Godwin *et al* 1981). The recently developed twin beam and stepped beam mole ploughs have helped reduce the beam surcharging penalties and the floating beam plough has eliminated the parasitic forces completely. The floating beam system has also helped overcome many of the grade and blockage problems.

Childs (1942) and Ede (1961) showed conclusively that the mole foot on a floating beam plough, is capable of maintaining a regular grade, regardless of significant changes in soil resistance or surface level, providing it runs parallel to grade. The beam/tractor hitch position, and hence the beam itself on a floating plough, is very vulnerable to displacement if the power unit pitches over surface irregularities. These beam displacements have a serious effect on channel grade and need to be minimised. The Silsoe College floating beam plough described by Spoor *et al* (1987) minimises these displacements by introducing a smoother frame between the plough and the tractor as shown in figs 1 and 2.

The mole plough is hitched through a pin jointed connecting link to the centre of the smoother. This arrangement ensures any displacement at the plough hitch, is only half that at either of the smoother extremities. The smoother itself is hitched to the tractor immediately beneath the rear axle, so that the smoother is isolated from any tractor front end pitching. Using this arrangement it has been possible to reduce the grade variation when compared with scrubbing beam ploughs, as the mole plough traverses local undulations. In addition the grade changes which do occur are considerably less abrupt which helps reduce the risk of mole channel collapse.

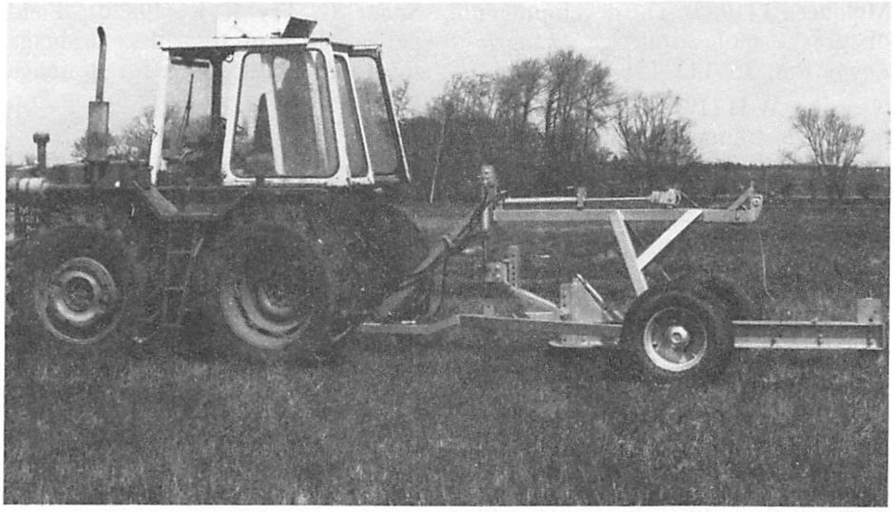


Fig 2 Floating beam mole plough designed at Silsoe College

The working depth of the floating plough is adjusted by varying the height of hitch and line of pull until the required depth is achieved. By changing the hitch position on the central smoother mast whilst moling is in progress, the working depth can be altered, allowing the mole channel to be installed on a grade different from that of the general land slope. In this way graded mole channels can be installed on level surfaces.

Other developments in the lower cost drainage area include the introduction of a wheel type soil slitter (Shelton), which leaves vertical slits approximately 20-30mm wide to function as drains. In addition, the gravel filled mole technique has been developed in Ireland by Mulqueen (1985) and provides stable drainage channels in soils too unstable for traditional moling.

5 Traffic and machinery management developments

Scientists have expressed concern about the possibilities of soil structural damage and compaction arising from increased soil loadings. Their comments however, have never been taken particularly seriously by most farmers and manufacturers in the past. This situation has now changed and there is an increasing realisation on all sides of the need to control compaction levels and of the benefits that could accrue from this. Such control not only improves the soil and the crop, but also reduces mechanisation inputs and makes soil and water management operations much easier. Mathematical models are now becoming available such as those by Seig (1985) and Smith (1985), to assist in the prediction of likely compaction levels.

The extent of soil damage under given soil moisture conditions is very dependent on the magnitude of loads, pressures, speeds and slip imposed through machinery running gear. Particular attention has been paid to the last three and significant advances made. Special purpose low ground pressure vehicles for operations such as spraying and fertilising are now common and very low pressure tyres have been introduced for tractor operations.

Some tyre manufacturers are revising their recommendations on minimum safe operating pressures for field operations. Reductions up to 0.3 bar have been possible in some cases without detriment to the tyre. The increased tractor power available facilitates higher speed operations and tractor manufacturers are addressing the problem of controlling wheel slip. These are all extremely valuable developments.

On the machinery side, the introduction of the vari-width plough (Kverneland) makes it much easier to match the implement and tractor correctly under a wide range of field conditions. This not only improves output but also allows optimisation of forward speed and slip. The increased number of combination implements also assists through reducing the need for multiple passes. Many of these additional passes are often executed under very vulnerable weak soil conditions.

The outstanding problem from a soil damage point of view is that of weight, which is responsible for deep seated compaction in soils and is difficult and expensive to alleviate. In the absence of achieving weight reductions, one approach is to contain damage to local sacrificial areas by restricting the highly loaded vehicles to traffic lanes only. This concept of controlled traffic has useful applications well beyond the heavily loaded vehicle situation. Developments in controlled traffic techniques are still in the early stages, although increasing numbers of farmers are confining large capacity trailers to headlands and bed systems have been used in various forms for many years. There are two current approaches, the first aiming to modify conventional equipment for operation on specially prepared traffic lanes and the second based on the use of gantries spanning 12-15m. Successful development of the controlled traffic concept would provide the opportunity to satisfy the often conflicting soil requirements of the crop, soil and water conservation needs and mechanisation operation with a minimum of compromise.

Conclusions

There have been many interesting and useful developments during the past few years all leading to improved and easier soil and water management. Many problems still remain to be solved. Experience over this period suggests very strongly, that greatest progress will be made in future, by combining the fundamental knowledge in areas such as soil physics and mechanics with the available inventive and development skills.

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Tractor hydraulics and implement control

R Bellanger

Summary

THE new range of tractors from Massey Ferguson, designated the 3000 Series, incorporates electronic draft control to give superior performance and efficiency in field operations.

The system replaces the previous mechanical draft control.

The way it is used and the advantages it brings over the current systems are described.

The principle and the operation of the MF designed Datatronic unit is also described. This unit has the ability to control wheel slip automatically, when it exceeds a driver-selected, pre-set percentage, by over-riding the draft settings.

1 Electronic draft control

The Massey Ferguson 3000 Series tractor uses an electronic draft control (EDC) which is now available commercially.

This system is made up of the following items:

i) an electro-hydraulic proportional valve to feed the lift cylinders for the three point linkage,
ii) an inductive displacement sensor to measure the angular position of the cross-shaft,
iii) two force transducers, one at the connecting point of each lower link,
iv) a control panel to allow the operator to set the mode of operation,
v) an analogue circuit for comparing the operating conditions to the settings on the control panel and for sending the resulting lift or lower signals.

As the technical description of this system has been described before (Hesse and Schrader 1984, Hobbs and Hesse 1980), it was thought logical to concentrate the main topic of this paper upon the detailed operation of the new system.

1.1 Control panel

The control panel of MF 3000 series tractor is shown in fig 1. The main switch on the top right permits the selection of one of three operating modes: up, stop and down.

When selecting "up", the linkage is lifted to its maximum permitted height. This height is selected by the operator using the maximum height knob which is at the top left of the panel. It is normally set to the highest possible setting and only in rare circumstances, such as with some pto driven machines, would one want to restrict the lift height.

When selecting "stop", there is no action by the control system on the linkage.

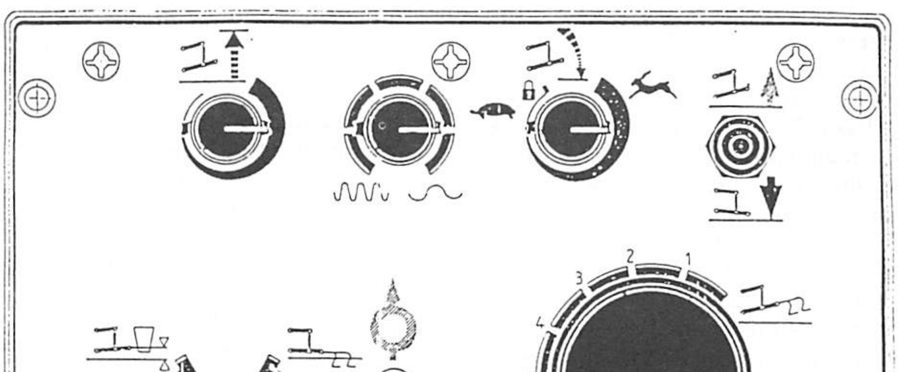
When selecting "down", the implement is lowered to the normal working position.

When attaching the implement, the operator may have to adjust two controls:

i) the maximum height (if necessary),
ii) the maximum lowering speed which is adjusted by the knob just to the left of the main switch.

The choice of lowering speed depends upon the relative weights and inertias of the tractor and the

Fig 1 Electronic draft control panel



Regis Bellanger is Manager of Advanced Research, Massey Ferguson Engineering, Beauvais, France.

implement, and also on the surface conditions.

Before starting field work, the operator must select the type of control he wants using the intermix knob which is on the bottom left of the panel. This selection can be varied from pure Position Control to pure Draft Control with intermediate positions. From an electronic point of view, the variation is continuous between the two extremes but a mechanical detent has been added to give preselected ratios in order to assist the operator.

This selection is mainly implement dependent. A mouldboard plough would typically be operated at setting 5 or 6, a chisel plough at setting 4 and a subsoiler at setting 3.

During field work, the driver can adjust the working depth of the implement by the main control knob at the bottom right of the panel.

The final control is the one second from the left of the top row. This is a sensitivity knob which in reality varies the width of the dead-band of the system.

Two light emitting diodes indicate when the lift and lower commands occur. By watching these, as well as the implement, the driver can adjust the sensitivity knob to get smooth and regular work without unnecessary corrections.

This type of control panel is typical of present day electronic draft control systems, and by giving easy adjustment of control parameters, it allows good results to be obtained when working in the varying conditions that can be met when operating a tractor.

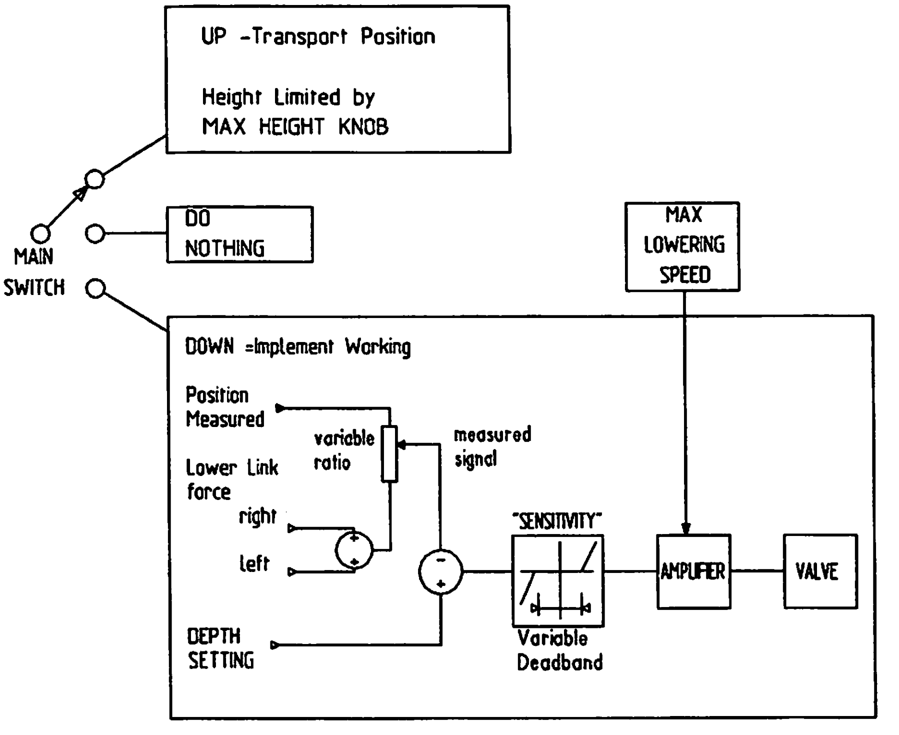


Fig 2 Overall control diagram

1.2 Overall control diagram

The overall organisation of the system shown in fig 2, can be deduced from the description already given of the controls.

Basically, in the down position on the main switch, the forces measured at the two lower links are added together and combined in proportion with the signal from the cross-shaft (position signal) to generate a measured signal. For example, at position 4 on the intermix knob, the measured signal will consist of 60% draft signal added to 40% of the position signal. This signal is then compared to the point selected on the depth knob and an error signal is generated.

This signal is then amplified by a fixed gain amplifier/controller and fed to the control valve. Overall control is achieved by varying the dead-band. This is different from most control systems where one generally tries to minimize dead-bands.

The controller, in fact, has three zones: lift, lower and do nothing.

The last is not the least important, particularly in the case of open-centre hydraulics.

With a narrow dead-band, the signals coming from the force transducers will generate opposite direction commands at a very fast rate. There is no need for the linkage commands to follow these quick variations because:

i) they disappear quickly,
ii) their duration is too short for the linkage to actually move.

If we assume a tractor with open-centre hydraulics (operating at 55 l/min) pulling a plough which generates 50 bar in the hydraulic cylinders through weight transfer, then a small dead-band will permit the generation of lift/lower commands much faster than 1 Hz, without actually affecting the plough.

Lift commands can occur in one third of this time and an approximate calculation shows that 1.5 kW of energy is wasted in the hydraulic circuit (not to mention component wear).

1.3 Comparison with mechanical draft control

The operating principle for these electronic draft controls is simply an electronic duplication of the mechanical systems that have been developed over the years.

There is no fundamental difference and the improvements obtained with electronic systems comes from their ability to perform the same function more accurately.

i) the hysteresis in the draft measurement system is drastically reduced,
ii) the controls are more easily adjusted whilst working,
iii) new possibilities for adjustment are available — such as dead-band — to match the operating conditions more closely,
iv) features such as lift and lower at the flick of a switch, although available on some mechanical systems, facilitate operation. As well as an improvement in operator convenience, there is also an improvement in efficiency at headlands.

This is now possible because of the increase in the number of adjustments compared to the mechanical systems.

The system is based on analogue electronics as are most systems on the market today. There is no doubt that future developments will be based on microprocessors for their calculating power is increasing rapidly.

From an engineering point of view, the overall performance could be refined and better sensing techniques used, but for the large majority of conditions this electronic draft control will satisfy the requirements. However, setting controls is of no great interest to a tractor driver and already, the cost of the control panel is about the same as that of the electronic circuit.

The direction of evolution will probably be more in reducing the number of adjustments by using more complex control techniques which are not, of course, possible with mechanical systems.

2 Automatic wheel slip control

This controller is part of the display system that has been developed by the Central Electronics Group of Massey Ferguson. Because of the cost of the system and the sensors, it is an optional extra on all 3000 series MF tractors and is called commercially "datatronic".

The "datatronic" system displays the following information: engine speed, true vehicle speed, wheel slip, pto speed, fuel consumption/hour, fuel consumption/acre, acre/hour, cost factor, acres worked, fuel consumed, fuel remaining, distance, counter next service.

Amongst others, the sensors include a radar system and a wheel shaft rotational speed sensor. These allow computation of instantaneous wheel slip, and then it is a logical step to follow this with electronic draft control as a slip limiter. Thus, when the system is active, the operator's setting of the draft control can be over-ridden by the slip controller when the wheel slip exceeds a pre-set limit.

2.1 System description

The general arrangement is shown in fig 3.

Radar

The radar unit is commercially available. It uses the Doppler effect on a 24 GHz microwave emission to generate a frequency proportional to true ground speed. In the mounting arrangement used, the ratio is 27.3 Hz per km/h.

Wheel-speed

A conventional variable reluctance magnetic pick-up is installed near the crown wheel of the rear axle differential unit. It measures a frequency proportional to the average rotational speed of the two rear wheels. Dependent on the tractor model and tyre sizes fitted, this frequency varies from 12 to 14 Hz per km/h.

Datatronic

The two sets of information above are interfaced to this unit which performs all the computations. It is a 6803 microprocessor based system, where operating parameters can be saved in RAM backed up by a lithium battery.

The processor, through a digital-to-analogue converter, outputs a voltage which can artificially raise the depth set point of the electronic draft control system.

It should be noted that all the operating settings of the electronic draft control system remain effective except for the set-point which alone can be varied. Thus the effect is the same as if the driver was slightly changing the position of the control knob. This is, of course, what he would do if he had no automatic control and he found that wheel slip was excessive.

2.2 Settings

Firstly, it should be noted that the two sources of information alone do not allow the computation of wheel slip because the effective wheel diameter must also be known.

The operator must re-calibrate the unit each time he changes a parameter such as tyre pressure. This is done by driving the tractor at approximately 4 to 6 km/h in a straight line in a non-slip condition and by pressing a switch for about 4 seconds. During this period, the radar information is compared to the wheel speed and (assuming zero slip) the corresponding tyre rolling radius is computed and stored in memory. This value will then be used as a reference to computer actual wheel slip.

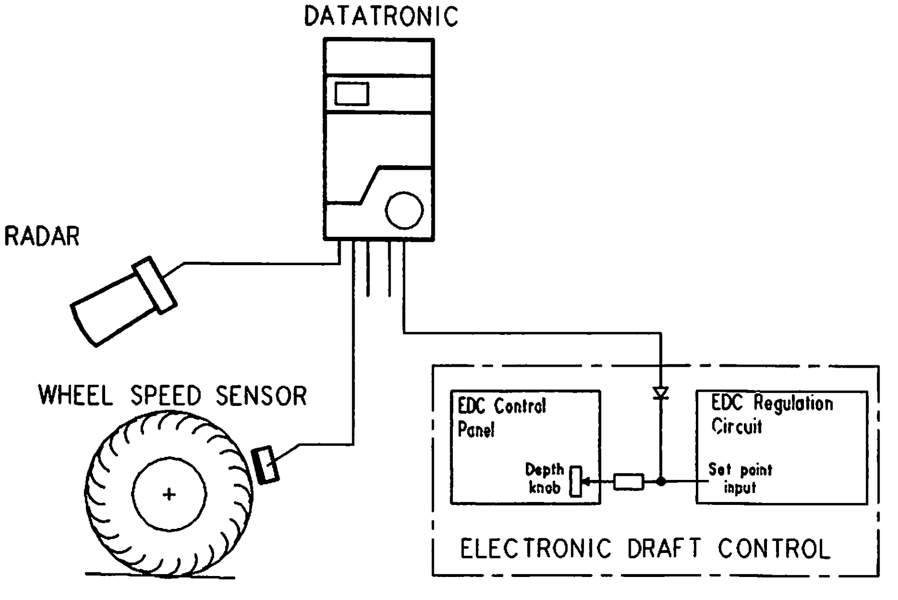
In normal operation, the driver has two commands:

i) Wheel slip controller.
This is activated by pressing a membrane switch and a light emitting diode indicates whether the controller is disabled or not. Whenever the unit is switched "off", the controller is disabled at the next power-up so that an untrained driver can use the tractor without being affected by the reactions of a system he does not know.

ii) Wheel slip limit.
By selecting the corresponding function on the panel and pressing a switch, the driver can adjust the limitation of wheel slip. This value is adjustable in steps of 3% from zero to 99%, although practical range is from 15 to 39%.

Further information is available to the driver through another light emitting diode which indicates when the slip controller over-rides the setting of the electronic draft control.

Fig 3 General arrangement of Datatronic and electronic draft control systems



2.3 Operating method

The driver starts work and sets the electronic draft control in the normal manner. He sets the slip value to the level at which he wishes the slip controller to become active. He then turns the system "on" by pressing the membrane switch. The controller will be on "stand-by" as long as the slip is below the pre-set limit. If the conditions deteriorate to the point where wheel slip is excessive, the controller will raise the depth set-point until the slip is below the requirement and the light emitting diode will come on to show that this is happening.

2.4 Overall control diagram

It will be easier if fig 4 is considered firstly in a stabilised condition where wheel slip is excessive and permanent correction is required to the depth setting.

The theoretical speed is computed from the wheel speed and the memorised wheel diameter (from the measured rolling radius). The true speed is computed from the radar signal. From these values, the actual wheel slip is computed every 100 ms. This value is slightly filtered before being compared to the slip-limit, to generate a slip error.

The controller, from the slip error value to the output, is a slightly modified PID (proportional, integral, derivative) controller. A first block generates a lead-lag compensation, and its result is fed through a proportional block.

The lead-lag output is also fed into another proportional block whose gain is dependent on wheel speed. The result is integrated. The output is the sum of these two values. This is then converted into an analogue/signal which is fed into the electronic draft control as a set-point value.

Start-up

When the slip is below the slip-limit, the control system is in standby condition. It monitors slippage but does not over-ride the operator's set-point. At this time, the system has to detect this setting to become active. It progressively and quite quickly raises the output until the detection circuit signals that it exceeds the operator's setting. This value is then stored in the integral block and the normal control starts from that initialising point. In other words, the operator's setting of the depth control is taken as the start point.

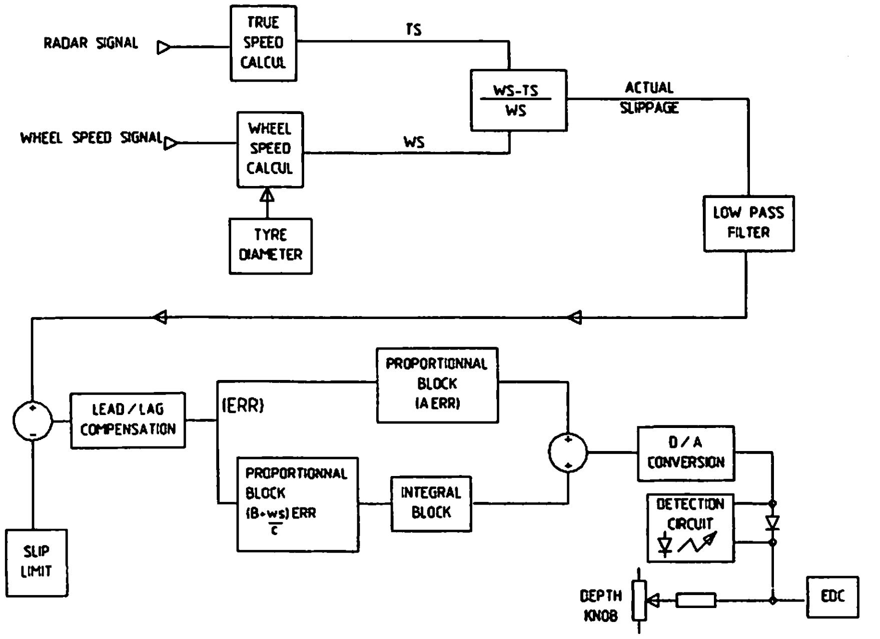


Fig 4 Overall control diagram

2.5 Usage

A system of this type is a valuable complement to the electronic draft system.

It is only "complementary" because the draft control loop adjusts quickly to a change in operating conditions such as tractor attitude, whereas the slip control loop is inherently slower because of the measurement techniques and of the tractor behaviour itself.

An experienced driver could achieve the same results as the datatronic unit but constant attention would be required throughout the day.

Datatronic control offers many advantages:

i) Efficiency is improved because a reduction in wheel slip has a direct effect on productivity.
ii) Tyre wear is reduced.
iii) Because one can work at the limit of the prevailing conditions, it allows the driver to continue working beyond the point where weather conditions would normally cause him to stop.
iv) When operating in fields with wet spots or on hillsides, there is a major reduction in the driver's fatigue.
v) A relatively inexperienced driver can achieve optimum tractor performance.

3 References

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Spray application technology

P C H Miller

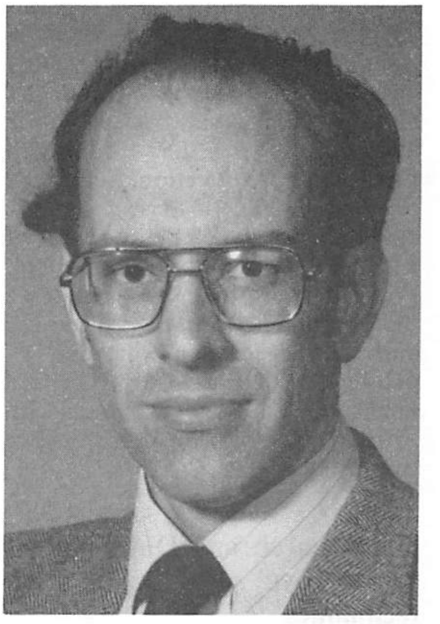
Summary

FINANCIAL and environmental pressures coupled with a need to improve human safety have been important factors influencing the design of improved chemical application systems. Better uniformity and timeliness of spray application should lead to reduced chemical dose rates with resultant savings in costs and pollution risk.

Laser based equipment has been developed to determine the physical characteristics of sprays and these are now being related to the application requirements for many treatments, although a better definition of the biological requirements for crop protection is required in a number of cases to fully utilize these techniques. Mathematical models are now available to aid the machine designer in identifying the contributions of different physical parameters in spray transport and deposition processes. Electrostatic charging and air-assisted systems can alter the trajectories, impaction and retention characteristics of a spray, and machines using such techniques have been developed.

Analytical models are available for boom suspension design. Such models enable a suspension geometry to be designed with known stiffness and damping characteristics to support a boom with given physical parameters. Passive suspensions isolate the boom from the higher frequency movements of the spraying vehicle and can be designed such that the boom is aligned with the transverse axis of the vehicle at low frequencies. To align the boom with the ground profile, an active attitude control is incorporated by making one of the links in a universal twin-link suspension adjustable. Signals from ultrasonic proximity detectors mounted on the boom determine the attitude with respect to the ground and adjustments are made via a control system and 12 volt actuator.

The paper briefly reviews areas of spray application system designs where technology and innovation are likely to have an impact in the next five years.



1 The need for improved spray application

The incentive to improve spray application techniques has three components; financial, environmental and human safety.

The value of UK pesticide sales in 1985 totalled £367M which represented an increase of 6.7% on the previous year and a 78% increase since 1980 (British Agrochemical Assoc 1985). Of the total area sprayed, 83% was in cereal crops and almost all crops, cereals and others, were sprayed more than once. The cost of crop protection chemicals forms a significant part of the variable costs of production of many farm crops. Examples for some of the main arable crops are: winter wheat 40%, sugar beet 10% and main crop potatoes 11%. There is therefore the potential to make significant input cost savings if chemical dose rates can be reduced without significantly reducing the level of pest and disease control.

Environmental and human safety factors are more difficult to quantify. Results from work such as the Cereals and Game Birds Project have shown increases in the size and range of insect and flora species in field boundaries which have not had spray applied to headland areas. Data relating to damage from spray drift is imprecise. Many alleged incidents are unproven with claims and disputes settled privately. Some environmental damage results from accidents at the time of application or failure to observe codes of practice. Incidents in which the poisoning of wildlife is suspected are monitored by the Ministry of Agriculture and by the Institute of Terrestrial Ecology (British Agricultural Assoc. 1985). Pesticides were detected in 45% of the 240 incidents involving vertebrates investigated by MAFF in England and Wales in 1983/84 and in the same period 61 honey-bee incidents were attributed to pesticide poisoning and involved 465 colonies of bees.

Data relating to the extent of operator contamination on a national scale is also difficult to obtain. In 1984 the Health and Safety Executive investigated 32 incidents of suspected pesticide poisoning among farmers and agricultural workers and 11 of these incidents were confirmed. However, this almost certainly does not represent the full scale of the problem because of the inherent under-reporting of such incidents. Measurements by the Operator Protection Group at the MAFF Harpenden Laboratory (Lloyd *et al* 1986) have shown that when spraying with hydraulic nozzles and using a spray vehicle with a cab, operators are typically contaminated with between 0.1 and 5.0 ml/h of spray liquid and can inhale between 0.001 and 0.012 ml/h. High percentages, often over 95%, of this contamination is on the hands of the operator. Significantly higher contamination figures were observed when there was no spraying vehicle cab.

Developments in crop protection chemicals have resulted in products

Paul Miller is Head of the Chemical Application Group at AFRC Engineering, Silsoe.

which have an increased biological activity. This is reflected in the quantity of active material sold in the UK which in 1985 was 27,500 tonnes, 9% less than in 1984 (British Agrochemical Assoc 1985). Herbicides accounted for 65% of this active material.

Considerable attention has recently been focused on pesticides and their application because of the implications of the Food and Environment Protection Act which received the Royal Assent in July 1985, and for which detail Codes of Practice are currently being drafted. Provisions within the Act relate to the use of only approved products and approved combinations of products, the use of specified application techniques and with operators of demonstrable competence.

2 Research and Development to improve spray application techniques

There are three components to improved spray application, namely:

(i) the targeting of spray to reduce drift and wastage,

(ii) the uniformity of deposit on the target,

(iii) the timeliness of application.

Improvements in handling systems on the spraying machine may also reduce the risk of operator contamination.

In this paper I will consider only ground crop sprayers which consist of: a spray generating system — usually a nozzle; a boom from which such devices are mounted; a pump and pressure control system; and a tank with an associated filling and agitation system. The use of engineering plastics in boom, nozzle and sprayer component manufacture has been a feature of recent developments. Although advances have been made in the technology used in pumps, pressure control systems, tanks, filling and agitation mechanisms particularly with respect to the materials of construction, most of my detail presentation relates to boom and nozzle design parameters. In the space available for this paper only a few significant developments are discussed.

For a number of crop/pest/pesticide combinations the spray target in terms of site, dose and drop size is known as a result of both field work and basic studies. However there are still many cases where the precise target is not known and where further biological work in conjunction with engineers is required to formulate the specification for the spray application system.

Improvements in the uniformity of spray application and timeliness should lead to lower chemical dose rates. In making dose rate recommendations, the chemical manufacturer must allow a safety factor to account for both a lack of uniformity and incorrect timing and improvements here should enable this safety margin to be reduced.

Timeliness of application is directly related to work rate since constraints imposed by the weather and stage of crop growth limit the time available for spraying. For example the average number of days available for spraying cereals in April over the period 1971–1980 was 15 assuming a maximum allowable wind speed of 4.6 m/s (Spackman 1982). If this maximum were increased to 6.2 m/s the number of days increases to 22 showing that application methods which produce sprays that are less affected by the wind would considerably improve the chances of a timely application. The potential for improvement in spray application work rate is illustrated in fig 1 which shows the effect of increasing forward speed and boom width and reducing volume application rates. Such data was obtained from a computer logistics model (Audsley 1986) which enables the effects on work rate of up to 34 variables of the spraying system to be evaluated.

3 Technological developments

3.1 Physical spray characteristics

It has long been recognised that the size distribution of drops determine the trajectory, impaction, retention and drift potential characteristics of a spray. Larger drops often have higher velocities and can bounce and be reflected from plant leaf surfaces whereas small drops may follow air currents around a leaf surface without being deposited. Considerable research and development has been aimed at controlling mean drop size and drop size distribution and relating these to target requirements. Spinning disc units have been widely used and many nozzle developments have this objective. The velocity and volume distribution within a spray cloud and air movements associated with spray formation are also important parameters affecting spray transport and deposition.

Ten years ago the measurement of drop size was cumbersome, labour intensive and had limited accuracy often depending on the characteristics of collecting surfaces. The introduction of laser based spray cloud analysis systems initially caused considerable confusion because different types of instrument took a different type of sample, either spatial or temporal, and produced different answers depending on the velocity distribution within the spray cloud. An analysis (Frost and Lake, 1981) showed that temporal and spatial samples could be related providing that the velocity /size relationship at the point of sampling was known. Recent developments have led to spray analysis systems based on the Laser Doppler Anemometer (Hislop 1986) in which the size and velocity of drops in a region defined by intersecting lasers is measured. Optical systems determine the diffusion patterns of light from within the sample area and hence determine particle size distribution and drop 'flux' density as well as velocity distributions. The computer analysis systems associated with these measuring techniques can provide data relating to both spatial and temporal samples.

Work to relate different measurements of the physical characteristics of spray clouds, particularly drop size distributions, has made progress recently but it is not yet possible to get good agreement in all circumstances. So as to provide both chemical manufacturers and their customers with a means of relating the drop size characteristics of different spraying systems, a comparative system has been introduced (British Crop Protection Council 1986) based on five size categories which were related to the performance of standard hydraulic nozzles. Such a system, although crude, represents a significant first step in relating the physical characteristics of a spray to the required target coverage for a particular chemical treatment. Extensions to this approach should enable measured parameters such as drop size and velocity or nozzle size and type to be specified along with other application data.

3.1.1 Electrostatic charging systems

The electrostatic charging of a spray

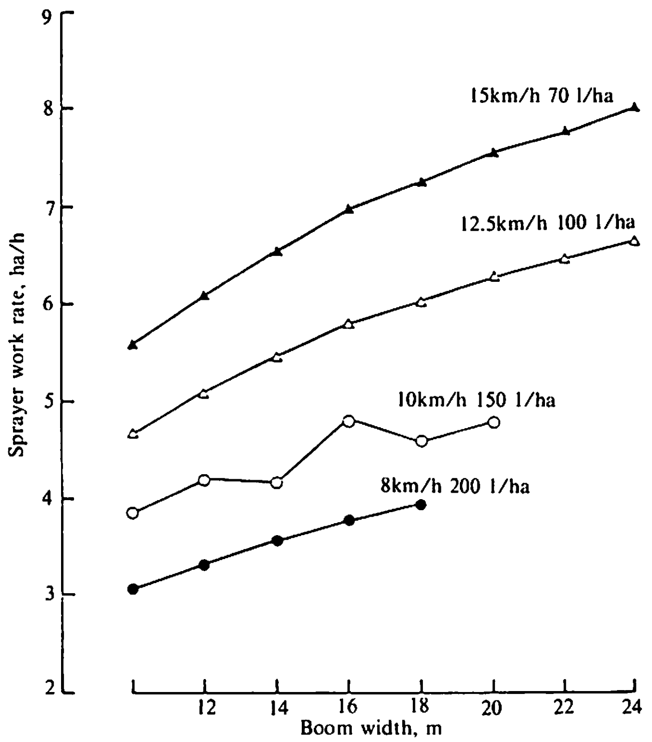


Fig 1 The effect of boom width, forward speed and volume application rate on sprayer work rates

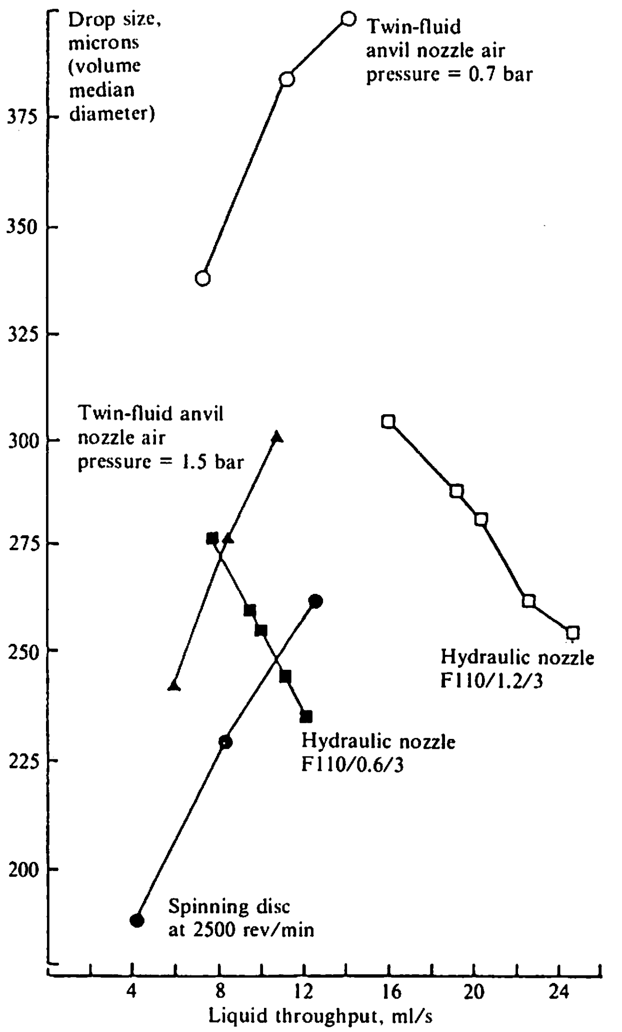
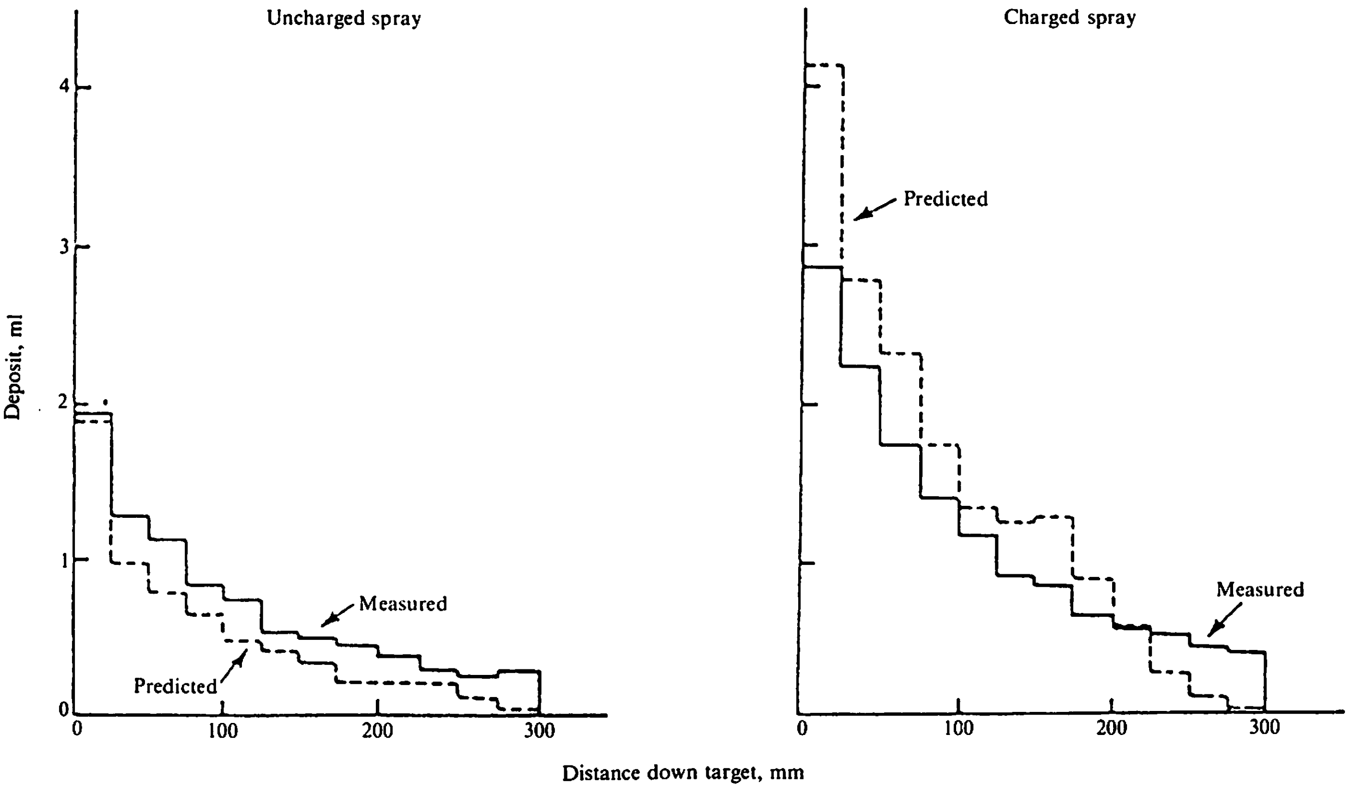


Fig 2 Drop size/volume relations for different spraying systems

Fig 3 Measured and predicted spray deposits on parallel plate targets sprayed with an uncharged hydraulic nozzle



gives rise to two extra force components capable of altering the trajectories of spray drops, namely image forces between an earthed target and a charged spray drop and space charge forces which results from the action of an electrostatic field generated by a cloud of spray acting on an individual charged drop.

For a simplified earthed parallel plate target with a uniform space charge of ρs (C/m^3), the electrostatic forces on a drop with charge q are given by (Law 1987) Image force between charged drop and earthed target,

$$f_i = \frac{q^2}{16\pi\varepsilon_o x^2} \qquad ...(1)$$

and

Space charge force on drop resulting from an electrostatic field,

$$f_c = \frac{q\rho_s x}{\varepsilon_o} \qquad ...(2)$$

where x is the distance to a plate and ε_o is the permittivity of free space.

Electrostatically charged sprays may increase target deposits, improve uniformity because of the mutual repulsion of particles charged with the same polarity and reduce spray drift. Developments in micro-electronics have meant that controlled high voltage sources can be produced relatively cheaply and in a compact form and this has led to the development of a number of systems for producing charged sprays using a range of methods. The features of these systems are detailed in an extensive literature. Induction charging systems for sprays produced by hydraulic nozzles and spinning discs have the advantages of relatively low charging voltages and operation with a wide range of formulations.

Field trials with experimental, prototype and production equipment to electrostatically charge sprays have given variable results (Cooke *et al* 1986). In some experiments equivalent or improved control to that obtained with full dose, full volume rate treatment has been achieved using charged sprays at lower volume rates. In others, improvements in pest control achieved with electrostatically charged sprays have not been detected. Measurements have shown that charging can reduce spray drift by more than 40% in some conditions (Sharp 1984) but again results have been variable.

Three main engineering factors influence the performance of charged spraying systems:

(i) The structure of the crop canopy. There is often little free space that can be occupied by the charged spray — i.e. ρ_s in equation 2 will be small and the space charge force component also very small. This is particularly so for cereal crops at the later growth stages.

(ii) Constraints imposed by the physical performance of the charging system in terms of drop size, velocity and charge level. In practice the charge on a drop may be proportional to its radius to a power, ie

$$q = k\, r^n \text{ where } 1.5 < n < 3.0 \qquad ...(3)$$

depending on the charging system (Hadfield 1987).

Small drops may have high charge/mass ratios with low velocities and hence are retained at the top of the canopy whereas larger drops with higher velocities may penetrate the canopy but have insufficient charge to change trajectories and so deposit patterns are similar to those with uncharged sprays.

(iii) Compatibility with existing boom sprayer systems in terms of unit mounting, chemical formulation, energy consumption and practical operation.

The use of electrostatic charging continues to offer the ability to alter spray trajectories and deposition patterns advantageously and to reduce drift but further research and development is required to develop practical systems. It is possible that charging may be combined with air-assistance or other systems to give improved application performance and the challenge to the engineer is to produce such units at an acceptable cost. A detailed knowledge of the biological requirements for improved application is required as the basis of a specification for this work.

3.1.2 Air-assisted systems

Relative motion between an air stream and a spray drop gives rise to a drag force that tends to make the spray drop travel at the same speed as the air stream. This drag force is given by

$$\frac{C_D\, \pi\, \rho u^2\, d^2}{8} \qquad ...(4)$$

where ρ is the density of the air, u the velocity difference and d the diameter of the spray drop. CD is the drag factor which is related to the Reynolds number which is dependent on the flow. Drops take time to reach a final velocity in an air stream and this is given by

$$T = \frac{\rho_L\, d^2}{18\mu} \qquad ...(5)$$

where ρ_L is the density of the liquid and μ is viscocity of air.

Small drops sprayed into slow moving air stream slow rapidly and with low vertical velocities have little energy to penetrate dense crop canopies. The trajectories of such drops are also prone to wind disturbance leading to spray drift. Large drops have higher velocities and are able to penetrate dense canopies but may not be subsequently retained on plant leaves.

The formation of spray from most nozzle systems, particularly hydraulic nozzles involves movement and entrainment of air associated with the spray formation. To improve crop penetration and reduce drift a number of systems have been developed which incorporate an additional downward air stream in the region of spray release. The use of air blast sprayers for fruit spraying is common with the best spray deposits being obtained with relatively large volumes of low velocity air. A commercially available ground crop sprayer used propellers mounted beneath spinning disc units to increase the vertical component of drop velocities. A more recent machine uses a curtain of air generated from outlets along an inflatable bag on the boom. Hollow cone nozzles spray rearwards into the downward air current with the air being provided by a pto driven adjustable axial flow fan. In these designs it is necessary to match air velocities to the target geometry. To impact on a surface a drop must penetrate the surface boundary layer and the depth of still air that can be penetrated can be determined from equation 5. High air velocities tend to stream leaves in the direction of the flow and reduce the effective area of the spray target and may result in spray being carried away in deflected air streams.

Air may be used to aid spray formation in twin-fluid nozzles with an increased entrained air component to assist subsequent spray transport. Twin-fluid nozzle designs are common in commercial paint spraying but have not been widely adopted in agricultural field spraying, probably because of the complexity and the need for a compressed air supply. A twin-fluid nozzle has been used as the basis of an electrostatic charging system (Law 1978) and a recent development by Cleanacres in the UK has used a twin-fluid anvil type uncharged nozzle.

The main advantages claimed for the Cleanacres system are:

(i) a relatively fine spray can be produced without using a small orifice which is prone to blockage, and,

(ii) the drop size can be varied over a range of values for a given liquid flow rate depending on the air and water pressures at the nozzle as shown in fig 2, enabling some matching of target drop size requirements independently of other application parameters. The system has a similar drop size/flow rate characteristic to a spinning disc but the drop size distribution is more like that from a hydraulic nozzle.

It should be noted that the measurement of drop size with this nozzle poses problems because some of the spray drops contain air bubbles which cannot be recognised as such by most drop sizing techniques. This type of nozzle therefore enables some independent control of spray quality with flow rate but requires up to 350 W of power to provide the air for each nozzle.

There is currently little published data on the magnitude and distribution of spray deposits from recently developed air-assisted systems, but a number of field and laboratory studies are in progress.

3.1.3 The use of analytical models to predict spray movement

Mathematical models have been developed to relate physical variables in a spray generating device to trajectories and deposition. Such models do not aim at absolute accuracy on a leaf by leaf basis but establish the relative significance of different system variables.

This approach has been valuable when studying the effects of electrostatic charging on spray drop trajectories when the effects of changes in physical spray properties can be difficult to assess experimentally. For example, in a model developed at AFRC Engineering (Dix and Marchant 1984), the forces due to gravity, air drag, an electrostatic field, the forward speed of the spraying unit and a simplified wind profile in the region of the nozzle are considered. The electrostatic field strength is determined by iteratively solving Poissons equation for calculated drop trajectories in a two-dimensional grid system using a finite difference scheme.

Model predictions have been compared with laboratory measurements of the spray distribution on parallel plate targets sprayed with charged hydraulic nozzles and spinning disc systems (Hadfield 1987). Agreement between observed and measured total spray deposits has been good with an acceptable agreement in the form of the deposit distributions as shown in fig 3. Differences between measured and predicted results relate to the simplifying assumptions made when structuring the model and concern transient electrostatic effects and the simplified air movement in the region of the nozzle which does not model the air turbulence and wake effects associated with the movement of the boom and spray vehicle.

The turbulent movement of air is a major factor influencing spray drift and random walk type models have been used to describe the movement of drops in atmospheric turbulence (Thompson & Ley 1983). The trajectories of individual drops are traced to predict the downwind drift of a range of drop sizes when the drops are subjected only to turbulent air movements. Each trajectory is considered over a number of time steps with the drop velocity w in the i+ 1th time step given by

$$w_{i+1} = \alpha w_i + \beta + V_{s(i+1)} \quad ...(6)$$

where Vs is the settling velocity, β is a random velocity component and

$$\alpha = \exp(-\Delta t/T_L)$$

Δt is the time step and T_L the Lagrangian time scale which is a characteristic of the turbulence experienced by a drop. Equation 6 is valid if the time step Δt is much greater than the response time of drop as given in equation 5 but less than T_L.

Spray drops from many nozzle types have high velocities when leaving the nozzle (15–20 m/s for a conventional hydraulic nozzle) and therefore the drop trajectories close to the nozzle are mainly a function of velocity at formation and the velocities of entrained air rather than wind turbulence. As the drop velocity is reduced by air drag so the effect of turbulent eddies increases. A model to account for drop movement including the region close to the nozzle is being developed at AFRC Engineering. Close to the nozzle trajectory, calculations are based on momentum and air drag considerations with turbulent disturbances whereas, further away from the nozzle a random walk approach is adopted. The change-over from trajectory to turbulent transport models is related to the terminal settling velocity of the drop. The simulation also predicts the evaporation of the drops and relates the turbulence structure to the crop and meteorological conditions.

The use of models to aid sprayer design can be illustrated by considering the effect of changing hydraulic nozzle angle in an inductively charged electrostatic system. Changing from an 80° to 110° nozzle angle will change trajectories, drop sizes and charge levels and will enable operation with a lower boom. The predicted quantity of spray airborne 1m from a nozzle 0.5m above a target and in a transverse wind of 2m/s is reduced by approximately 80% by electrostatic charging with both 80° and 110° nozzles mainly because of attraction of spray within 10cm of the top of the target. With 110° nozzles, spray volumes 1m downwind are between 1.8 and 2.0 times greater than with 80° nozzles at the same height. If the height of 110° charged nozzles is reduced to 0.35m, which gives a comparable overlap pattern, airborne spray volumes are reduced to 36% of those with 80° charged nozzle.

Changes in airborne spray volumes arising from the different drop size distribution and charge level that would result in practice from changing from an 80° to 110° nozzle is found to be relatively small in comparison with the effects of boom height and give a further reduction of 3% in airborne spray compared with a charged 80° nozzle. The model indicates that although total airborne spray volumes are considerably reduced by charging, the vertical distribution is altered such that up to 45% of the airborne spray may be above boom height 1m downwind with a charged spray compared to almost zero in the uncharged case.

Predictions therefore indicate that there are advantages in terms of drift potential from using the wider angle nozzle in a charged system providing good control of boom height is maintained.

Experimental work has verified the conclusions drawn from using the model but has indicated that further work is required to obtain a better definition of air movements close to the nozzle and particularly of air entrained in the spray and displaced by the boom.

Future work will aim at developing techniques which will enable the performance of a range of boom designs and nozzle mountings to be investigated to identify systems which will reduce the risk of drift and maximise target deposits.

3.2 Boom suspension systems

The need to isolate spray booms from the high frequency rolling and yawing movements of the vehicle is now well recognised and all but the very smallest commercial sprayers now incorporate some form of boom suspension. Isolation of the boom from the vehicle movements results in a more even coverage with less underdosing and overdosing. Reduced rolling movements allow the boom to be operated closer to the target with a reduced risk of tips hitting the ground, and so spray drift is reduced, and spray penetration into dense foliar canopies improved. Since a suspension isolates the boom from much of the vehicle movement, the cyclic stress patterns in the boom are reduced which in turn reduces the risk of fatigue failure.

The performance of a boom suspension is a function of its geometry and the characteristics of the suspended boom weight, position of the centre of gravity and the moments of inertia. Analytical models have been developed to provide a rational basis for boom suspension design (Frost 1984, O'Sullivan 1986, Frost & O' Sullivan 1986). This has led to the development of computer models which provide the basis for suspension designs.

The designer must decide on the required stiffness of the suspension which is related to the natural frequency. This is illustrated in the design of a twin universal link suspension (Frost 1984) which provides isolation in both roll and yaw. A design which is too soft will not allow the boom to align itself correctly with the tractor as it travels over sloping or undulating ground or as it turns on the headland. On the other hand a suspension which is too stiff will transmit an unnecessary amount of vibration to the boom.

A typical frequency response characteristic in roll (or yaw for the universal link design) is shown in fig 4. The significance of this suspension stiffness can be seen by using the model to predict tip movements for a suspended 12m boom when travelling over a single "square" bump 0.2m long at a speed of 8 km/h and these are plotted in fig 5.

The suspension performance is also affected by the degree of damping incorporated. The frequency response characteristic in figures 4 and 5 is for a suspension with a damping ratio of 0.8. A lower damping ratio will increase boom movement at the natural frequency and may result in the boom oscillating after an input movement. High levels of damping will limit boom movement at the natural frequency but will also increase the transmission of high frequency inputs. These effects are illustrated in fig 6 which plots boom tip displacements for a moderately stiff suspension again for a 12m unit travelling over a 0.2m step at 8 km/h. In a practical suspension design some damping will arise from friction in joints and in some cases by the need

Fig 4 Typical frequency response characteristic of a passive suspension

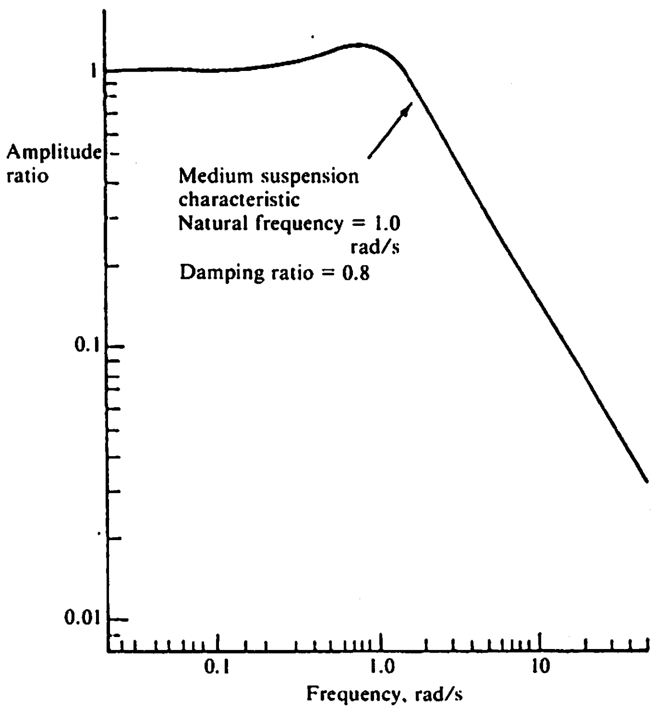


Fig 5 The effect of boom suspension stiffness

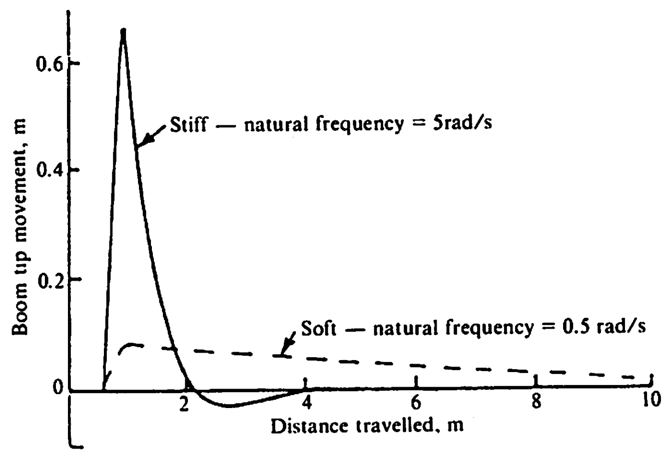
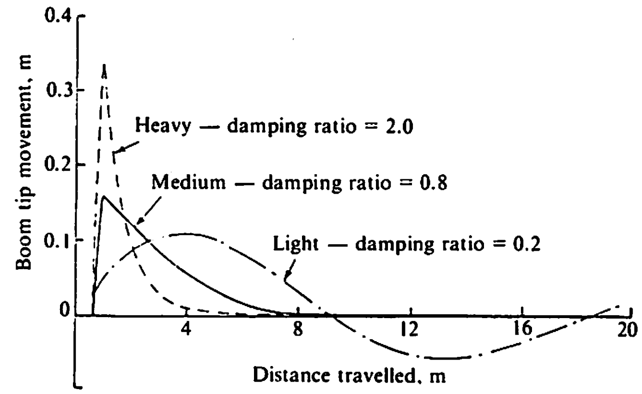


Fig 6 The effect of boom suspension damping



to deflect connecting hoses, but in many designs additional dampers will be required within the geometry to give the required performance.

Most boom suspensions fitted to commercial machines are passive in that they do not require external power. Twin link and gimbal suspensions can be designed so that at low frequencies, the attitude of the boom is aligned with the transverse axis of the spray vehicle; however there are conditions when the axis of the spraying vehicle is not aligned with the ground, for example, when operating in tramlines with unequal wheeling depths. To correct for this condition, an active attitude control system has been incorporated in the twin universal link suspension (Frost 1984) by making one of the links adjustable in response to signals from a control system.

The analytical model of the passive suspension has been extended to include this active element and this model then used for the design of a suspension control system with an adequate response time that is stable. Ultrasonic proximity detectors, developed for use with auto-focus cameras, measure the height of the boom at two or more points and provide an error signal relating to the angle between the boom and the ground. Height is determined by timing the return echo from an ultrasonic pulse and the echo signals obtained from a range of crop and soil conditions have been investigated.

A 12 volt screw-jack actuator has been used as the variable length link on prototype suspensions. This is driven at a speed proportional to the magnitude of the error signal to correct boom attitude. This relatively low cost actuator is adequate to support a wide range of boom sizes because:

a) the high frequency movements of the spray vehicle are isolated by the passive element of the suspension, and,
b) the weight of the boom can be supported by springs in parallel with the actuator so that the actuator loading is symmetrical about a mean zero load.

The performance of a boom suspension design can be verified using a sprayer instrumented with gyroscopes to record input and output movements of the suspension when operating over a range of surfaces. Fig 7 shows such data recorded with the twin link suspension and active attitude control supporting a 12m boom driven over a step input at 1.8 m/s. Measurements were made of vehicle and boom angles and have been projected to give vertical movements at the boom tip.

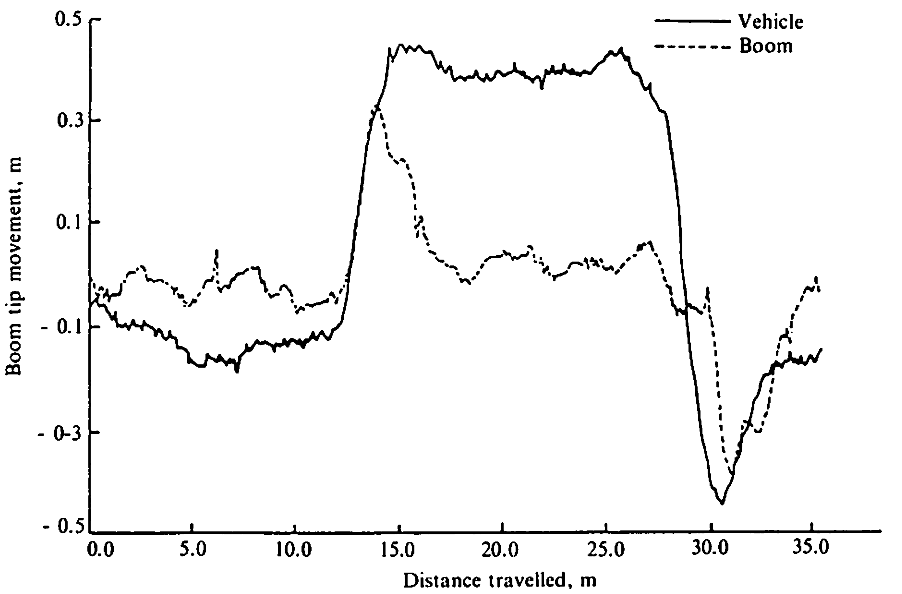


Fig 7 Measured boom tip movement when driving passively suspended 12 m boom with active attitude control over a step input at 1.8 m/s

4 Future developments

Most of the developments referred to so far have been the subject of some commercial exploitation. Work is also in progress which may result in new spraying machinery and components in the next five years.

It is likely that monitoring and control will become increasingly automated as sensors and control systems are developed and incorporated on sprayers. Most commercial methods of controlling chemical application rates alter the throughput of hydraulic nozzles by changing pressure in response to forward speed. Such a system has a relatively low turn-down ratio since volume throughput is proportional to the square root of pressure and changes in pressure significantly change the physical characteristics of the spray. Work is in progress to develop metering systems to vary the concentration of the active ingredient at the nozzle in proportion to speed while spraying diluent at a constant rate. An additional advantage of keeping chemical and water separate is that the need to dispose of unwanted diluted chemical is removed.

Most of the contamination of the sprayer operator occurs when loading and mixing the concentrated chemical. Effort is now being directed at establishing effective closed system designs which will enable metered quantities of active chemicals to be mixed in the sprayer without exposing the operator to the concentrated material. Combined with a metering mechanism, such a system offers considerable improvements in terms of operator contamination and the risk of environmental pollution.

The development of improved sensors that are able to distinguish between different types of plant and different plant conditions and that are low cost and robust, offer the prospect of only spraying the areas of a field requiring treatment. Sensors and monitoring equipment are already being developed to monitor field conditions and so enable local pest and disease predictions to be made, enabling the timing and targeting of spray applications to be improved. Computerised information systems can give access to crop production, disease and weed competition models which then form the basis of an economic assessment of proposed spraying programmes.

5 Conclusions

The incentives to improve spray applications are considerable with significant financial, environmental and human safety benefits to be obtained from the application of appropriate technologies.

Significant progress has been made in applying advanced technologies to spray application problems including the development of systems for determining the physical characteristics of a spray. Improvements in the quantity used and distribution of spray deposits and reduced drift may result from the use of electrostatics and air-assisted systems but some further research is required to develop these systems. The use of analytical models to identify the significance of different system variables will aid the development of improved application systems.

Boom suspensions have been successfully developed to isolate the boom from the rapid rolling and yawing movements of a vehicle. The use of an active attitude control system enables the boom to follow ground profiles in response to signals from ultra-sonic detectors mounted on the boom. The performance of boom suspension systems can be predicted by computer models which provide a valuable aid to the design of suspensions with given characteristics.

Future developments are likely to involve improved chemical metering and handling systems to reduce the risk of operator contamination and environmental pollution. Improved monitoring and control of field operations and the use of predictive models to evaluate the economic consequences of spray applications will further improve the utilization of crop protection chemicals.

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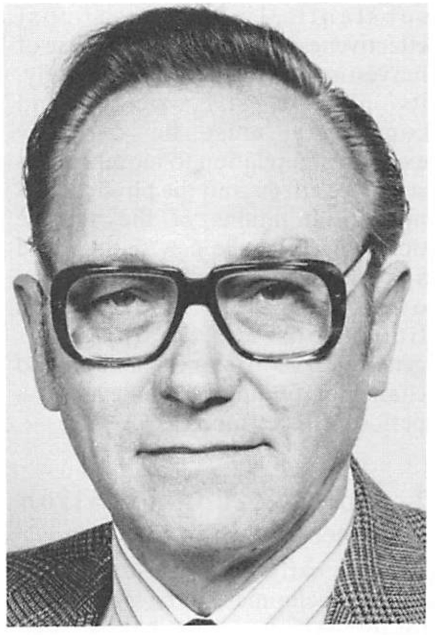
Innovations in harvesting equipment

W E Klinner

Summary

MECHANISMS employing new principles are being developed to make the cutting and comminution of forage crops more energy efficient. In the conditioning of grass, the concept of abrading the crop cuticle by steel and plastic elements has proved to be cost effective. In difficult climatic conditions facilities for the immediate spreading of the crop, especially from wide mower-conditioners, would increase drying rates even more.

Development progress in the harvesting of cereals by *in situ* stripping of the grain is encouraging. On-going work is aimed to improve the performance further of replacement stripper headers for combine harvesters and to extend the range of crops which can be harvested satisfactorily in this way to include herbage seeds, oilseed rape, pulses and some special crops. Further advances are desirable in the development of machines for the utilisation of crop residues. A press capable of briquetting uncomminuted straw in the mobile and stationary modes could make important contributions to the economy of straw use if the performance objectives of outputs of 6–8 t/h at an energy consumption of 40–60 MJ/t can be achieved. To increase the scope which machinery designers have for developing more cost effective equipment, tractors generally need to be given more features to encourage the systems approach.



1 Introduction

In the UK the total area devoted to the growing of grass, cereals and other seeds amounts to over 90% of all agricultural land. Conserving surplus forage for winter feeding and harvesting seed crops involves successions of seasonal operations which are of the utmost economic importance to farmers.

Impending changes in cropping practices and production methods, aimed to bring the supply of food into better balance with consumption in EEC countries, will make it more difficult to maintain adequate profit margins. Pressure will increase to raise the quality of farm products and at the same time to reduce inputs. Losses and waste will need to be curbed even more than in the past, and fewer men and more cost effective methods and machines will be required.

Table 1 indicates the size of the UK market for machinery associated with the harvesting of forage and cereals and also the sales trends in the last decade.

Mower-conditioners have seen a substantial and sustained rise in popularity during the last decade, as have self-propelled forage harvesters on a more modest scale. In the last five years double-chop forage harvesters have staged a come-back and big balers are taking an ever increasing share of the total baler market.

Because of the current economic uncertainties, sales of several types of harvesting machinery are likely to remain at relatively low levels in the short term future, both east and west of the Atlantic. This provides an opportunity for objective analysis of the efficiency and cost effectiveness of machine systems which are presently in use and of alternatives

Wilf Klinner is a Consultant Engineer and was formerly Head of Field Machinery Division, NIAE, Silsoe.

Table 1. UK deliveries to dealers of forage and grain harvesting equipment since 1976, as reported to the Agricultural Engineers Association.

Type of machine	1976	1981	1986
Mowers — drum	4633	3306	2530
— disc	1798	424	400
— flail	672	117	75
Mower-conditioners	559	2087	2300
Forage harvesters			
— metered chop self-propelled	27	49	60
— metered chop trailed	1233	2123	1650
— double-chop	1075	194	400
— flail	342	96	NA
Combine harvesters	3159	1859	1770+
Balers — small piston	6140	2092	1350
— large roll and piston	1147	884	2770
Self-loading forage wagons	NA	563	110

\+ *estimated retail sales circa 1900 units*
NA not available

which could replace at least some of them. A risk to be avoided, if possible, is that escalating first costs become a serious disincentive to machinery renewal and extended use. The possibility of design simplification needs to be borne in mind constantly, and greater sophistication should be limited mainly to applications which can substantially increase cost effectiveness and safety. In the case of harvesting equipment particularly, its physical size, weight and complexity must be carefully examined in relation to mobility, soil structure effects and the physical and mental limitations of the average operator. Effective new designs and systems, which successfully overcome deficiencies and limitations of the previous generation of machines, have a good chance of finding buyers, even in a period of recession.

2 Forage conservation machinery

Since the early 1970s research related to the development of new machines for forage conservation has had high priority at the NIAE, now the AFRC Institute of Engineering Research (IER). Specific objectives have been energy saving, high levels of effectiveness, simplicity of design and functional reliability.

2.1 Mowing mechanisms

Several years of study at IER have been devoted to increasing understanding of the cutting process in which unsupported crop stems are severed on impact by high speed knives. At normal cutting speeds of approximately 80 to 90 m/s most rotary mowers give an acceptable performance in normal crops and conditions. However, their energy requirement is usually several times that of reciprocating shear-cutting mowers. Under ideal conditions, with perfectly sharp knives, good cutting can be achieved at around two thirds the normal knife tip speed and then at proportionally reduced energy consumption (Tuck 1976).

Were it not for the risk in mowing of occasional contact with the ground, or with foreign objects lying on it, improvements in mower design and performance could be easily effected. It is the provision of impact protection for knives and knife mountings of novel designs which is so difficult to achieve by simple means. However, new approaches are being explored, because a reduction in cutting speed of at least half, but ideally two thirds, would bring important advantages. In particular it would make it possible to attach suitably shaped components to the knife-carrying discs so that simultaneously the cut crop is conditioned by them to increase drying rate. Moreover, rotary mowing would be less likely to cause damage to machinery and injury to personnel, and worthwhile energy savings could be achieved.

2.2 Mower-conditioners

During the last decade the change from hay to silage making has been marked, but this does not seem to have affected the increasing popularity of mower-conditioners, probably because of their widely, though not universally applicable cost effectiveness (Audsley 1986). However, the justification for purchase is likely to have changed, with a bias in many cases now towards the preparation of windrows suitable for collection by forage harvesters.

In Europe the most popular mechanisms for grass conditioning are based on the concept of cuticular abrasion, as developed at IER in several alternative forms. In an early series of field experiments during successive seasons in Bedfordshire the overall average increases in field drying rate recorded with the original steel-spoke conditioning system were 60% to the 40% dry matter content (dmc) level and almost 50% to 65% dmc. These improvements were accompanied by an average increase in dry matter yield of 11.7% relative to the traditional system of haymaking (Klinner 1975). For the same type of conditioner favourable results were reported subsequently also from Devon, Scotland and several countries in Continental Europe.

Later designs of IER conditioners employ plastic elements (Klinner and Hale 1984), and these have proved to be adequately durable and in some cases more effective than the steel V-spokes. Recent work at the Scottish Institute of Agricultural Engineering (SIAE), now the Scottish Centre of Agricultural Engineering (SCAE), has drawn renewed attention to the additional benefits to be obtained in terms of faster field drying under difficult climatic conditions from spreading cut grass. The work has also confirmed that windrowing two conditioned swaths into one, at or immediately after cutting, can retard field drying to a rate lower than that of unconditioned grass left in single swaths. Moreover, the shape of the swath and the stubble length can affect drying rate (Spencer 1987).

In the light of the continuing demand for ever wider mower-conditioners, careful consideration needs to be given to the way the treated crop is placed onto the ground. Ideally there should be a choice between spreading the crop and forming it into swaths. Much better results could be obtained if only farmers were prepared to increase the wheel spacing of their mowing tractors and conditioner manufacturers provided better adjustments of swath width. With very wide machines single swath formation is entirely appropriate when mowing light crops for silage, particularly second and third cuts; however, in heavy crops a preferable alternative would be to displace the crop sideways so that consolidation by the tractor and machine wheels during the next bout is avoided.

Where high output is of paramount importance, as with contractors, a good case can be made on economic and practical grounds for attaching two mower-conditioners to the same tractor, rather than using one very wide machine (Tuck *et al* 1980). Combining a front-mounted with a rear-offset-mounted mower-conditioner gives many of the advantages and operating options of a self-propelled unit.

2.3 Forage harvesters

In recent years design improvements in commercially available forage harvesters have resulted in higher outputs, lower specific power requirements and safer operation. Particularly important and effective introductions have been multi-knife cylinders and metal detectors, to limit damage from foreign objects collected with the crop, and chopping by upward rather than downward rotation of the knife rotor. The latter limits potential damage even further and brings significant savings in energy requirement due to the conveying path of the chopped material becoming straighter and shorter.

Whilst the popularity of cylinder choppers remains high, that of flywheel choppers appears to be increasing, probably because of their inherently low susceptibility to machine damage, relative simplicity, and the high capacity of current models. The increased sales of double-chop harvesters may be associated with the ability of these machines optionally to pick up wilted crop or to cut direct. Interest in direct cutting harvesting systems is on the increase in the wake of the publicity given to the higher levels of grass utilisation recorded consistently with them since 1983 in Northern Ireland (Gordon 1985). This approach commends itself on grounds of simplicity and low cost, but requires a satisfactory solution to the problem of effluent disposal.

At IER the forage harvester mechanism has been examined in terms of pick-up efficiency, chopping performance, crop conveying function and energy requirement. A high speed pick-up system has been developed which allows even short crops to be collected efficiently and soil contamination to be minimised. In conjunction with the pick-up, metallic and non-metallic foreign objects can be sensed in the intake region and automatically rejected back onto the ground before they reach the feed mechanism to the chopping rotor (Klinner 1985).

Low energy demanding comminution mechanisms under development are based on the crop being aligned first across the direction of flow. The actual length reduction is achieved by either reciprocated or rotated knives slicing the crop layer at close spacings across the width of the feed duct. Laboratory rigs and experimental field machines are used to optimise the important design and operating parameters. Rotary knife speeds of <3 m/s and spacings of 20 and 25mm have given acceptable chop lengths and outputs of up to around 60 t/h at a saving of about 40% in comminution energy, compared with conventional cylinder-type forage harvesters (Knight 1985). In on-going work, particular attention is being given to the cutting edge profile of the slicing knives, to the sharpening mechanism and procedure, and to damage protection. A suggestion for a simple slicing type harvester is shown in fig 1.

In relation to well established forage harvesters, it has been shown that most energy can be saved by conveying the chopped material mechanically rather than pneumatically into the bulk trailers. Of the mechanical conveyor systems studied so far, a sandwich type belt arrangement has given throughputs of up to 40 t/h with sufficient delivery distance to enable normal silage trailers towed behind the harvester to be filled to capacity. The energy required was 25% of that needed by some existing pneumatic/impeller systems. Scope exists for the development of alternative forms of mechanical crop elevators and for design and performance improvements of pneumatic conveyors.

In the medium term future the basic approach to harvesting forage crops, including maize, is unlikely to change drastically, but there seems little reason to doubt that harvesters can be simplified and designed to have a specific energy requirement of possibly less than half that of some present day machines, with maximum outputs substantially higher. In the case of legumes, particularly lucerne, defoliation of the standing crop, followed by separate harvesting of the stalks, may become cost effective because of the potential for achieving higher levels of animal production and, in the longer term, for extracting protein for human consumption from the leaf fraction.

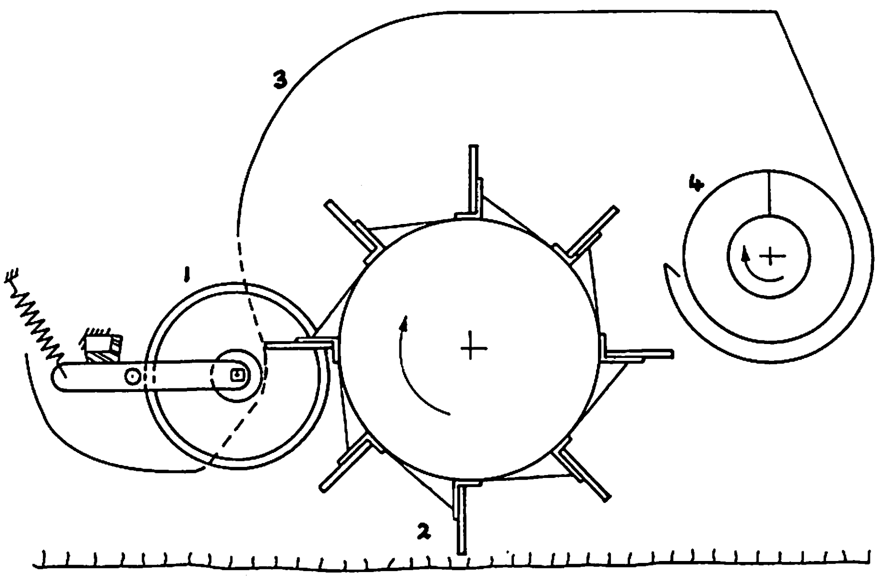


Fig 1 Operating principle of simple pick-up chopper, using knife discs, with collection auger for crop transfer into elevator

(1) Sharpened disc cutters
(2) Intermeshing pick-up rotor with resilient crop engaging elements
(3) Rotor housing
(4) Transverse conveying auger

3 Grain and seed harvesters

3.1 Combine harvesters

Over 80% of all combine harvesters sold are still of traditional design, but the pace of change is beginning to quicken in response to demands for ever increasing output. Because of the high straw yields of cereal and seed crops in Europe, practically all combine makers have gradually increased the diameter and width of the threshing drum and the straw walker and sieve areas. Some straw walkers have become steeper and more severely stepped, and in some instances agitators have been added to improve grain separation further by loosening the threshed straw layers.

In North America the conventional threshing and straw shaker systems have been replaced by large, axially arranged rotors surrounded by cylindrical concaves. The crop passes through the unit in a helical path, seed being detached and largely separated in the first section, and separation being completed before the straw reaches the exit.

The trend towards axial rotors for threshing and cleaning had not been followed until recently by any of the European manufacturers. Instead, two chose to replace the straw walkers of their largest models by a succession of transversely arranged rotors or cylinders, which draw the crop over suitably shaped concave grids. Claims for these systems are good performance regardless of straw condition and moisture content, effective separation at high throughputs and reduced susceptibility to the adverse effects of side slopes.

Two recently introduced models of combine harvester from an Italian manufacturer have a tangentially fed axial threshing and separating rotor behind, and parallel with, a fundamentally conventional cutting table. This layout avoids all of the straw having to pass through the whole machine, permits a compact overall design and allows an extra large grain tank to be readily accommodated.

3.2 Stripper harvesters

There is little doubt that further improvements to existing combine harvesters can be made in a number of ways. However, a drastically different approach is needed if substantial size and cost reductions are to be achieved without major output penalties. At IER it was thought that *in situ* stripping of seeds, which had been attempted repeatedly by others in the past, might provide a solution, provided known limitations could be overcome (Klinner 1986a). The most serious shortcomings of previous stripping systems were incomplete seed detachment, high losses and inability to perform satisfactorily in unfavourably presented crops.

The development at IER followed by first evaluations of an experimental stripper header for a conventional combine harvester have been reported already in *The Agricultural Engineer* (Klinner *et al* 1987). During a second season of field evaluations with a modified header confirmation has been obtained under different crop and field conditions of the effectiveness of *in situ* seed stripping by a rotary combing mechanism using slender resilient teeth with key-hole shaped recesses between each pair of teeth. Confirmed also were the favourable effects of minimal straw intake on combine output in cereals and in linseed and the reduction of header losses which become possible in laid crops, particularly barley. Additionally, trials in oilseed rape, herbage seeds and navy beans have indicated that in due course it should become possible to adapt the new stripping system to harvesting these crops satisfactorily, and possibly also others. Alternative forms of seed stripper configuration are shown in fig 2.

In the light of current appreciation it is thought that crop stripping mechanisms can find effective application as:

(i) *Retrofit headers for existing combine harvesters.* In principle any make and model of combine harvester should be able to take such headers, but in practice retrofitting may be limited to more modern combines on which the required driveline power can be readily provided at the front. There should be no difficulty with machines designed to take multi-row maize heads. For a time at least the weight and cost of stripping headers will be higher than that of conventional cutting tables of equal width.

(ii) *'New concept' combine harvesters.* The marked difference of stripped material relative to cut crop, in terms of its grain/straw ratio and the presence of free grain, makes it desirable in a stripper harvester to arrange and dimension the mechanisms for threshing, separating and cleaning more favourably than has been possible in conventional harvesters. Specifically, immediate separation of free grain, prior to threshing the collected material other than grain (MOG), would reduce the risk of grain damage and facilitate final separation. The threshing device needs to be capable of dealing effectively with short material. It should be possible to design new concept harvesters that are light and compact, thus overcoming to a substantial extent the main criticisms some farmers have of present day combines, particularly those of excessive size and weight and of high cost. New concept stripper harvesters will be expected to produce a clean grain sample and, consequently, they are likely to be of particular interest to contractors and large cereal growers.

(iii) *Tractor-operated stripper harvesters.* Full advantage of machine simplification and size reduction offered by the seed stripping concept will be taken if harvesters are designed to utilise a tractor as the power unit, either on the North American model as trailed offset machines but, ideally, as front-attached units. The latter configuration provides most of the operating advantages of self-propelled machines, and tractors in reverse-drive mode are particularly suitable in terms of mobility and machine supervision and control. The operating tractor could pull a grain trailer, which may be interchangeable or provided with transloading facility. If it is acceptable to carry out the final cleaning of the harvested grain at the farm, a worthwhile measure of simplification of the harvesting unit will become possible.

(iv) *Tractor-operated stripper collectors.* In cereals it has been found that the MOG collected with the seed is minimal in the first few days of combine ripeness. Consequently, where a schedule of timely harvesting can be maintained during most of the season, it may be economical to collect all stripped material and transfer it to the farm for storage and subsequent grinding into livestock feed, or optionally for separation, any final threshing which may be necessary and cleaning of the grain sample by stationary equipment. For this approach only a simple form of harvester is required comprising essentially a stripping unit and conveyor system. Consequently the equipment would be relatively light and inexpensive and could be designed to be attached to the operating tractor at the rear or front. This harvesting system may be of special interest to

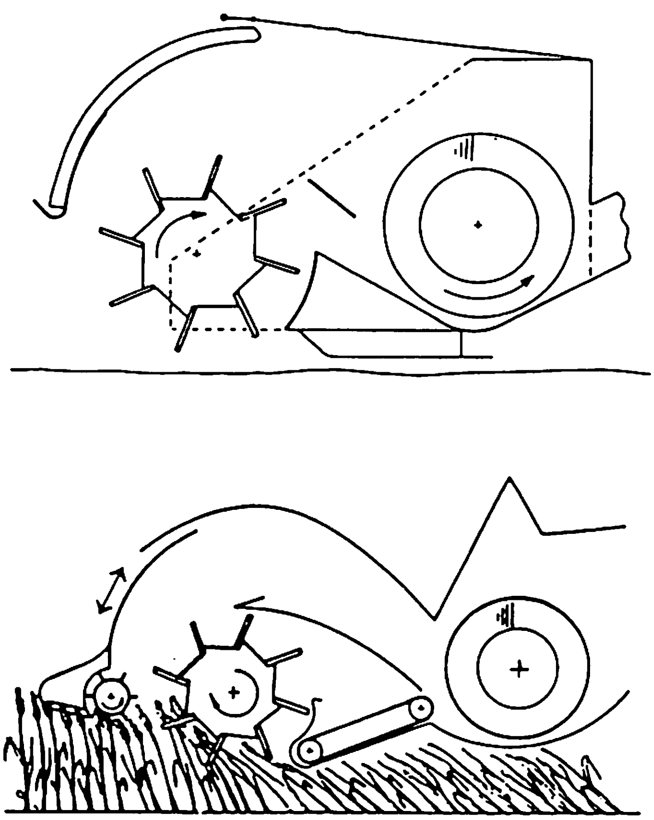


Fig 2 Alternative configurations of grain stripping combine header. Top: direct stripping with unaided transfer of material into collecting auger. Bottom: stripping assisted by feed rotor, with transfer conveyor linking stripping rotor and collecting auger

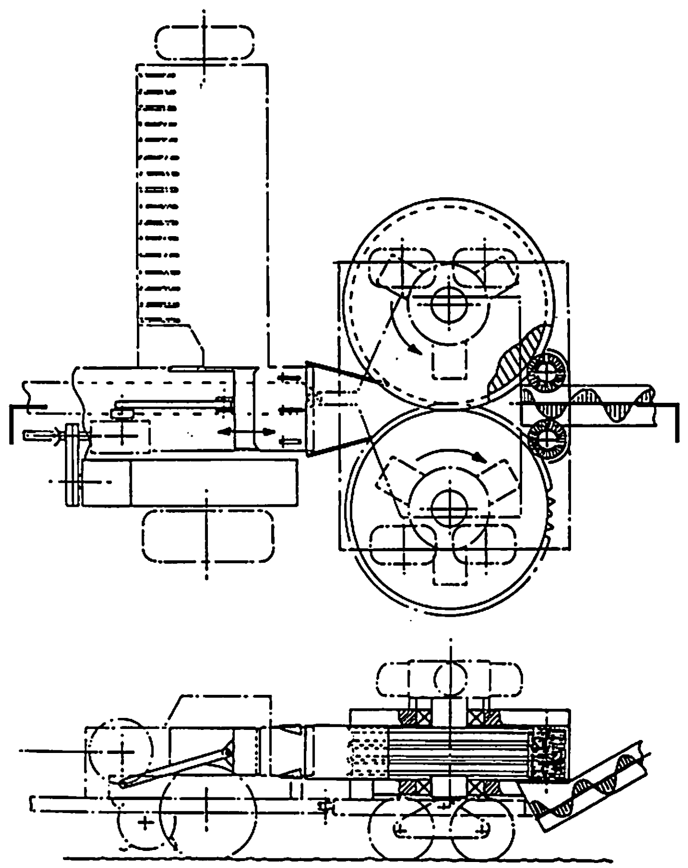


Fig 3 Proposal for a field-going, hydraulically driven twin-roller straw briquetting press, using principal components of a conventional baler for collecting and pre-compacting the crop. Top: plan view. Bottom: side view

livestock farmers, because the flag leaf, which can constitute the bulk of the collected MOG, has a nutritional value equivalent to good hay (Ramanzin *et al* 1986). If all or part of the harvested material is to be separated into grain and MOG, then stationary barn equipment need have a capacity which is sufficient only to process in 24 hours that quantity of material which was collected each day. The separated MOG may be pelleted or wafered with or without additives and supplements, or it may be burnt to generate heat for grain drying or warming buildings and stores.

(v) *Harvesters for special crops.* For crops with unusual growth habits and seed bearing characteristics, harvesters may require special designs of seed stripping, collecting and processing mechanisms. In particular, details of the stripping elements and the width and height dimensions of their supporting components may need to be matched to crop height and stem thickness. For example there is unlikely to be need for drastic differences in design between a stripper harvester for wild white clover and one for navy beans, but for harvesting by stripping off such crops as sunflowers or maize, or for the collection of flower heads, quite different design considerations would need to be applied.

(vi) *Rice harvesters.* For rice the stripping mechanisms probably need not differ substantially from those which are suitable for other cereals. The power units to which they may be attached can include pedestrian controlled two-wheeled tractors, four-wheeled tractors or tracked vehicles, in addition to conventional combine harvesters. Final separation and cleaning at the farmstead is likely to be acceptable initially in much of the third world. Should the resistance to uprooting of the crop during stripping prove to be insufficient in paddy rice, suitably shaped and positioned crop tensioning rollers can be used to increase it.

(vii) *Foliage stripper collectors.* Stripping mechanisms designed for seed crops are suitable also for the removal *in situ* of the leaf fraction from the stems of foliage plants. If required, alternative designs of elements can achieve the plucking or breaking off of laterals or of twigs from shrubs. Crops suitable for defoliation include lucerne, other legumes and culinary herbs.

The energy requirement of seed stripping headers for existing combine harvesters is several times that of conventional cutting tables and, on average in cereal crops, no saving of energy can be expected. However, in view of the high no-load power requirement of present day combine harvesters, worthwhile energy savings may result from new concept designs of combine and from tractor-operated stripper harvesters.

It would be a simple matter to make provision for the residue behind any crop stripping mechanism to be cut down and even windrowed or chopped, as part of the same operation. However, standing straw, in particular, dries much faster after rain than windrowed combine straw and consequently expense can be saved when burning or baling is intended. A tractor pulling a baler could have a swather at the front. Incorporating stripped straw residue presents no serious difficulty in practice, but its effects on different soils will need to be monitored over a period of years.

4 Machines for crop compaction

The majority of large balers on British farms are roll balers. Progress achieved by manufacturers in competition with each other has been commendably fast. A major advance has been the recent introduction of net wrapping, which has not only increased output potential through a reduction of unproductive tying time, but also has improved the appearance and weather resistance of the bales and greatly facilitated their use ex store. The next step already announced is a roll baler design capable of continuous output, and it should only be a question of time for bales to be discharged hermetically sealed in plastic skins.

The choice of balers making large rectangular-section packages has also increased and it is expected that they will take an ever greater share of the potential big baler market. Their relatively high cost would be justified better if the maximum attainable bale density, particularly in straw, were substantially higher. Potential would seem to exist for reducing first costs and running costs by simplification of the crop feed and distribution systems and through a reduction in bale chamber wall friction.

Unlike baling, the briquetting and wafering of crops has not progressed markedly in the immediate past. These forms of packaging have particular potential for the procurement of surplus straw as a raw material for industrial use. However, existing wafering and briquetting presses have a very high energy consumption, ranging from approximately 80 to over 200 MJ/t. To this must be added 30–60% for the energy needed to comminute the material first by either chopping, shredding or milling it. A further disadvantage of existing wafering presses is their relatively low output of from 0.3 to 4.0 t/h (Neale 1986).

At the IER an alternative approach to forming small straw briquettes is being developed (Klinner 1986b). It uses uncomminuted straw, and the bonding is achieved by inducing triaxial movement of the material during compression, leading to physical interlocking (Nation and Osborne 1986).

To put the new briquetting concept into practice, a twin roller press is being developed with the ultimate objective of producing a machine which is capable of being used in the field for harvesting straw directly and, optionally, in the stationary mode for processing baled straw. Indications from laboratory work with a scaled down press are that the energy requirement will be in the region of 50 MJ/t and that outputs of 6–8 t/h at relaxed unit densities of 600–700 kg/m^3 will be possible. A proposed arrangement for a mobile press is shown in plan and side views in fig 3. Crop is collected by a conventional pick-up, pre-compacted by a reciprocating piston, briquetted by two counter-rotating pocketed rollers and the briquettes are conveyed away by an auger.

Apart from the substantial saving of communition energy, the briquetting/wafering of unchopped straw has the advantage that any requirement for a long staple length can be met. If the straw is to be processed in comminuted form, shredding or milling the briquettes can be done at any time. Although unit densities of pressed briquettes or wafers are likely to remain lower by at least 25 to 30% than those of extruded wafers, which can exceed 1000 kg/m^3, the bulk densities of pressed products will be more than adequate to allow the legal load carrying capacities of bulk transporters to be fully utilised.

5 Tractor/machine interface

Many improvements have been made in tractor design and the facilities offered. The most recent innovation is the provision of on-board computers.

However, two important areas have not seen as much progress in recent years as would have been desirable. The first of these is the transmission of power to the land without causing smear and high levels of soil compaction. The second is the better adaptation of the tractor to the requirements of machine systems. It seems that ergonomic considerations have been confined to the operator's work place in a narrow sense, neglecting largely the additional requirements when machines become an integral part of the plant which is in the control of the operator seated on the tractor. For many tasks in the field and farmstead the reverse mode of operation would be more convenient, safer and more efficient, because the working elements would then be in the most immediate, clearest possible, natural field of vision of the driver. The arguments in favour of retaining the conventional mode of operation are getting fewer and less convincing. With 4-WD tractors, particularly when the wheels are of equal size, there is already an overwhelming case for only the reverse drive mode, ie forward control, to be provided.

Steps which can be taken in the short term to increase the versatility of present day tractors include lowering the bonnet line, so that the driver's view of the forward space is improved, and providing front attachment and drive facilities more widely. The ultimate configuration of the system tractor may be one in which there is symmetry about the longitudinal and transverse axes, so that the operator is placed centrally and all the options of machine attachment, supervision and control are available to be exploited to the full by the machine designer. Machine systems could then be given most of the advantages of self-propelled units. Provided the interchange of attachments is made rapidly and easily accomplished, and performance is of a high standard, multi-purpose systems may in due course gain favour. Based on tractors rather than special power units, as for example the combine harvester, they would be financially attractive. Since the advantages of self-propelled operation apply to high and low power demanding tasks alike, the usefulness of system tractors is likely to span a substantial size range.

6 Forward look

The economic problems facing farmers in the forseeable future make it desirable that investments in harvesting machinery became evermore cost effective. Consequently, tractor and machinery manufacturers stand to gain mutually from co-operating in product development projects and to do so from an early stage. Defining user needs and preferences and predicting initial product uptake are such vital prerequisites for commercial success that in-depth market surveys would seem to be economically justifiable in respect of most new products, but especially when substantial departure from convention is involved.

Acknowledgements

Valuable contributions from former colleagues to the IER developments referred to in this paper are freely acknowledged.

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Developments in milking machinery

F E Goldsmith

Summary

THE development of the milking machine is described from the invention of the two chamber teat cup 80 years ago to the present day. Recent developments are detailed in teat cup liners, pulsation controllers, vacuum regulators and micro computers for management systems.

1 Introduction

It is over 80 years since the introduction of the two chamber teat cup by Alexander Gillies and this break-through established the principle of allowing vacuum to be applied to the cow's teat to extract the milk, yet enabling the liner to be pulsated at the same time to minimise tissue damage and to prevent congestion of the blood vessels. Since that time most developments have been concerned with the application of this principle in various forms, and major work has been concentrated on auxiliary equipment rather than on the basic milking unit itself.

In the 1920s developments evolved around the bucket unit for milking cows in cowsheds with different pulsation systems varying from the Wallace bouncing ball in the teat cup to more sophisticated master pneumatic systems with pulsation controlled by a gear driven rotary valve on the vacuum pump. The 1940s heralded a trend towards milking in parlours mainly with abreast stalls and glass recorder jars. The 1950s saw a return to more basic systems with direct-to-can milking, but a decade later a radical change from can collection to bulk collection of the milk from the farm resulted in a rapid change from bucket to pipeline milking in cowsheds and from direct-to-can milking to pipeline milking mainly via recorder jars in parlours. In the 1970s the emphasis was on the ergonomics of the operator with much development work on new parlour design, in particular rotary parlours; however automation, particularly in the field of automatic cluster removal, enabled one operator to look after a large number of milking units which concentrated recent development towards herringbone parlours in their varied forms.

Recent research work has been concentrated on the action of the teat cup liner on the teat and on ways in which pathogens can be spread during milking causing new mastitis infections. Strong evidence that the liner movement itself can cause aerosols to be impacted on the teat end led Tolle (1975) in Germany and Phillips and Woolford (1975) in New Zealand to experiment with non-pulsating milking systems. In this country NIRD (1980) established the use of shields which, without interfering with the liner wall movement, protected the teat ends from impacts so reducing the penetration of the teat canal by pathogens. These have been commercially available since 1980. Meanwhile, other work at NIRD principally by Griffin and Grindall (1984/5), concentrated on the provision of non-return valves in the clawpiece to prevent the surge back of gas and liquids as the liner opened. Normal liner movement was originally preserved by introducing air bleeds in short milk tubes close to the junction with each liner. Later work concentrated on using the same claws with ball valves but without the air bleeds. This led to one of the most important developments this century and has been termed hydraulic milking. It should be remembered that the establishment of an air bleed as a definite feature in the milk claw was not commonplace until the mid 1950s and on the majority of machines a form of hydraulic milking occurred with the milk moving backwards and forwards with movement of the liners hence the need for use of backcords etc. to maintain cluster attachments. The development of hydraulic milking, however, establishes a new concept as the liner movement is arrested by the action of the check valve and the forces applied to the teat are different. This means further investigation is now required into optimisation of vacuum levels, pulsation rates and ratios, cluster weight and liner design.

2 Recent developments

2.1 Teat cup liners

Over the past two years the author has been involved with the design of a teat cup liner incorporating check valves at the base of the liner which, to date, have been used only with a conventional cluster having the normal air bleed maintained at the milk claw. The action of the check valve liner is shown in fig 1.

Investigations have indicated that a hydraulic action with such liners is obtained in approximately 80% of the time on 84% of the teats. Tests indicate that fluctuation at the teat end is increased and the mean vacuum level increased by about 12% over conventional liners used on the same machine. This results in increased peak flow rates but overall effects on total milking times have varied considerably. Increased peak flow rates may have an adverse effect on teat condition as we found when changing from high level to low level milking, indicating that a reduction in vacuum level may be an advantage when using check valves in the system.

Frank Goldsmith is Technical Manager of Alfa-Laval Agri Ltd, Cwmbran, Wales.

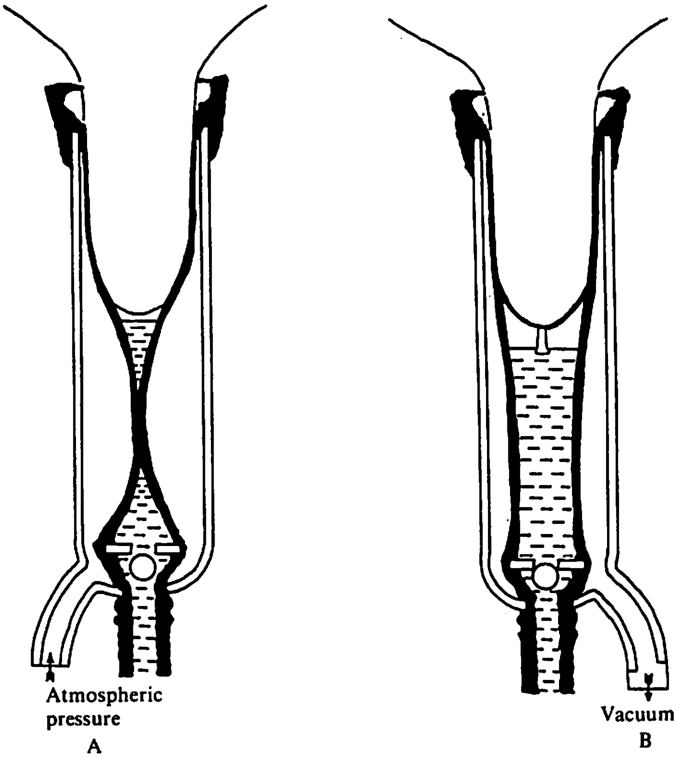


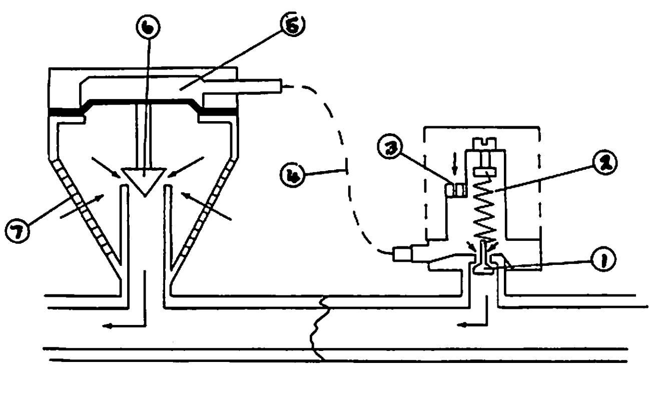
Fig 1 Check valve action in teat liner

A Check ball liner during 'd' phase of pulsation. Atmospheric pressure on outside of liner allows ball to drop from seating and for liner to collapse as milk is drawn out

B Check ball liner during 'b' phase of pulsation. Full vacuum applied to outside of liner plus liner tension cause liner to open and for check ball to seat. Amount liner opens is determined by milk flow filling liner and air leakage past teat

Fig 3 Servo vacuum regulator

When required level of vacuum is reached, valve piece (1) supported from spring (2) opens allowing air to be drawn out of the chamber and air to enter through fixed air bleed (3). If the vacuum level rises, valve piece (1) is opened further creating a vacuum in connecting tube (4) which is transmitted to chamber (5) in the main regulator. This allows the diaphragm to contract, lifting valve (6) so air enters the system through inlet holes (7). As soon as the vacuum level drops, valve (1) closes allowing air via inlet (3) to enter chamber (5) causing valve (6) to close.



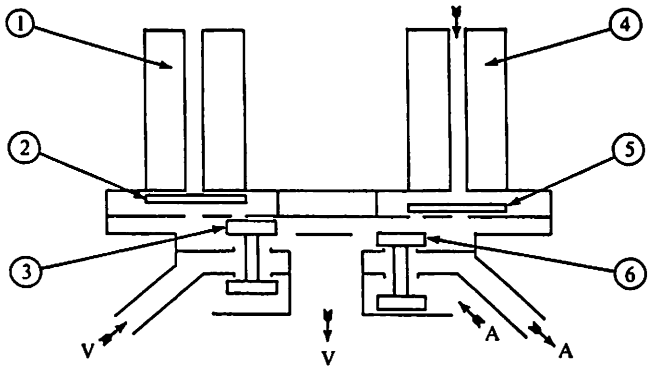
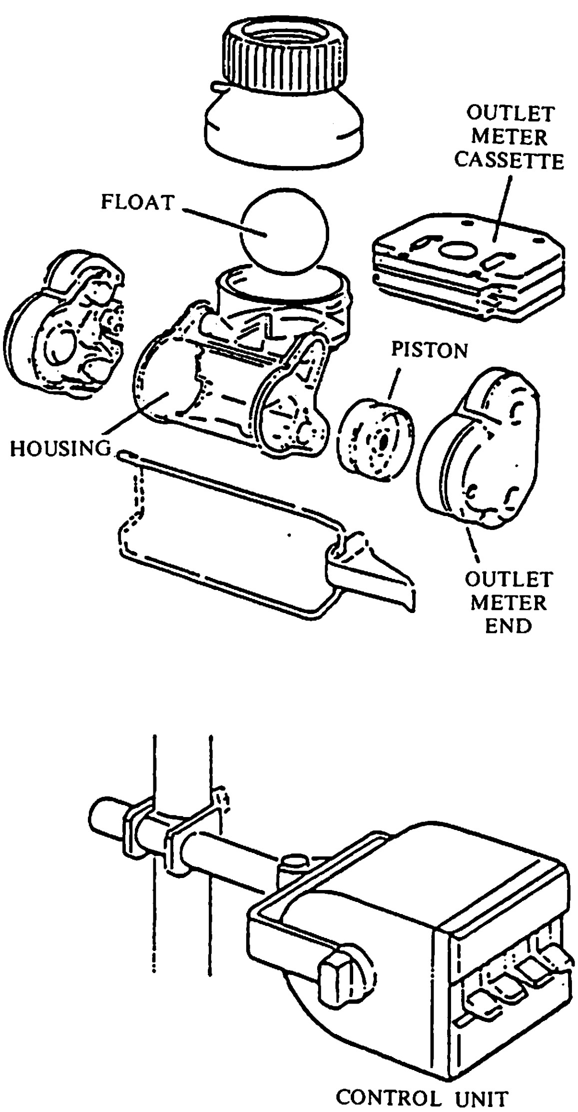


Fig 2 Electric pulsator for 2:2 milking

Solenoid (1) is energised lifting valve disc (2), closing off air vent through centre of solenoid and exposing vacuum port above membrane valve. Valve (3) lifts opening vacuum port to pulse nipple. Solenoid (4) is de-energised allowing valve disc (5) to drop, closing vacuum port and venting membrane valve to atmosphere via centre of solenoid valve. Valve (6) drops closing vacuum port and opening air inlet to pulse nipple

Fig 4 Main components of recording jar meter



2.2 Pulsation control

A trend back to electrically controlled pulsation systems has seen the utilization of quartz crystal timing technology to allow both master and individual pulsation systems to be controlled with great accuracy. The use of small solenoids actuating integral amplifying valves has allowed the air from pulse chambers of teat cups, which can be contaminated in the event of damage to liners, to be isolated from the controlling air system passing through the solenoids (fig 2).

2.3 Regulators

The weight or spring loaded single acting regulators are being replaced with two-stage servo-regulators. These new regulators have capacities far greater than the original types, but have the principal advantage of sensing vacuum level upstream in the main air pipeline and letting compensating air into the system downstream of the sensor; thus avoiding the problem of sensing pressure levels in a turbulent air stream as is the case with single stage regulators (fig 3).

2.4 Milk recording

Traditionally, recorder jars have been used as a means of recording milk in the majority of parlours in the UK. Initially these were suspended from spring balances but since the 1960s volumetrically calibrated glass jars have been used. These can be suspended from electronic strain gauges and the weight measurements indicated on a digital display or a TV monitor and a printout provided when the system is linked to a microprocessor. Cow numbers are entered into the system by the operator as the cows come into the parlour.

A flow recorder fitted at the base of the jar to measure the milk as it is transferred from the recorder jar is a recent development. As the air is separated from the milk within the jar, measurement of the single phase liquid flow is both accurate and comparatively simple, see figures 4 and 5.

There is however, a trend towards direct-to-pipeline milking in parlours with large bore pipelines of about 75mm diameter and much attention is being applied to the development of more sophisticated milk meters that record the milk as it is drawn from the cluster into the pipeline. Such recording devices are already available that can either give a digital display or are linked to a microprocessor, but as they have to deal with a two-phase flow of milk with entrained air it may be difficult to achieve an accuracy of greater than 5% with such equipment.

2.5 Management systems

Milk recording devices are of course an integral part of management systems now available which can be linked to automatic feeding systems and provide more herd management information without the necessity of more inputs from the herdsmen at milking time.

Alfa Twin, as recently introduced by Alfa-Laval, heralds a change from dedicated microprocessors and uses a Commodore 64 processor to collect data for milk recording from either strain gauges or digital milk meters and displays milk yield as it is given by the cows in all the milking stalls on a centrally placed monitor in the milking parlour. The processors will also control the in-parlour feeders to feed a pre-programmed individual ration of concentrate to each cow as it is identified by the operator keying

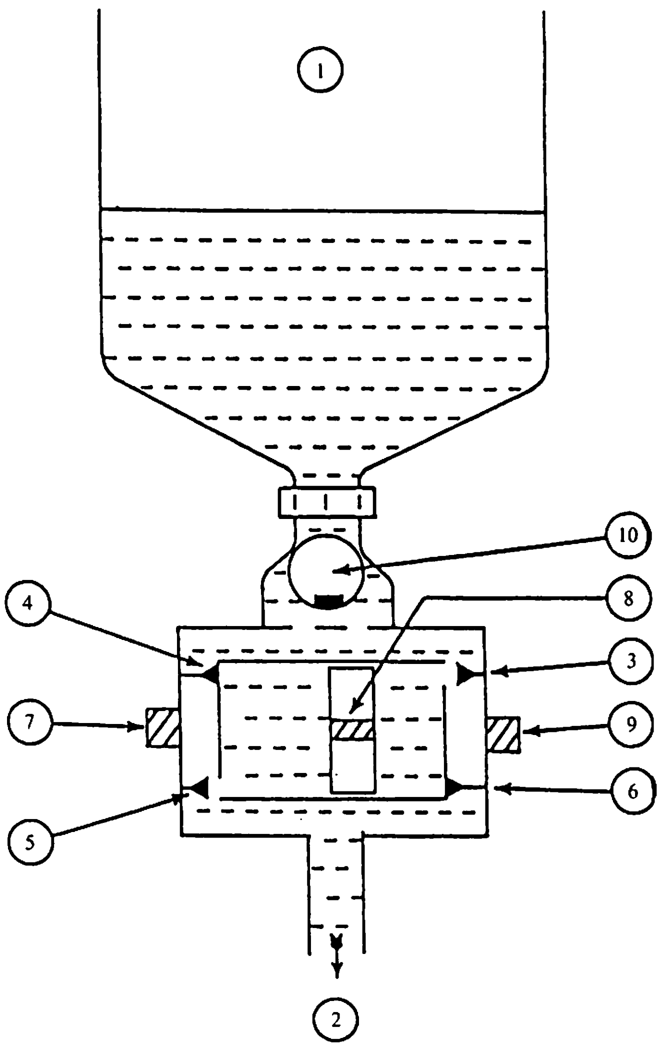


Fig 5 Recording Jar Meter

After milking space (1) above the milk is vented to atmosphere and outlet (2) opened to vacuum; milk inlet valve (3) is open, valve (4) is closed, milk outlet valve (5) is open and valve (6) is closed. The pressure difference across the inlet and outlet ports allows milk to be drawn out and carries piston (8) across until the magnet housed in the piston actuates magnetic sensor (7). This, in turn, causes the operation of a vacuum control system so that valve (3) is closed, valve (4) is opened, valve (5) is closed and valve (6) is then opened. This creates a pressure difference in the opposite direction so as more milk is drawn out the piston (8) is displaced towards magnetic sensor (9) and when sensor (9) is magnetised the valving is again reversed. The exact volume between the piston and the end cover enclosing the valves is equivalent to 100 gm of milk so that the changeover of the valving can be monitored by a vacuum/electrical converter and electronically counted giving a display of the amount of milk transferred. When all the milk has been transferred, magnetic ball valve (10) drops and all four valves are closed until the next quantity of milk is transferred in the cow number on a keypad suspended near the parlour entrance. Keying the cow number into the appropriate stall for feeding automatically links that cow number to the appropriate milking unit for the registration of yield which can be printed out after milking. A display menu allows appropriate data on any cow to be displayed or entered as required. Provided that cows are normally identified by the operator for feeding in the parlour, the system allows for the automatic recording of yield without any visual and audible signals to indicate the presence of pre-programmed alarm cows - i.e. cows treated with antibiotics in a particular stall as the cow entry is made. Such a management system using mass-produced processors and, making use of a normal operator function, allows a complete management system to be offered at a much lower price than the previous dedicated systems with automatic identification.

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Discussion at the 1987 Annual Convention

Questions following Paper 1. (G Spoor — Development in machinery and techniques for improved soil and water management).

R Fry (Land Drainage Contractors):

Q How can current information on soil mechanics best be disseminated widely to people with limited knowledge of the subject eg agriculture, recreation, amenity?

A *The commercial exploitation of research has always been a problem but it is encouraging that the results of agricultural research work are being taken up in different fields eg laying of oil pipelines.*

T C D Manby (Silsoe Consultants):

Q At one time, the Dutch carried out experiments with traffic lanes but ceased the work in preference to the use of low pressure wheel equipment etc. Do permanent traffic lanes have a future?

A *The use of permanent traffic lanes does not improve overall yield directly because the yield improvement from untrafficked soil equates with yield loss from the uncropped lanes. However, the use of traffic lanes may improve timeliness of cropping operations and hence subsequent yield. It is important to ensure that lanes are well cambered and drained by throwing each side of the roadway to the centre, otherwise the roadways get rutted, collect water and become useless.*

P Hemingway (Harper Adams College):

Q Is there a possibility of a new generation of cultivation equipment being developed which utilises the failure of the soil in tension rather than compression with subsequent savings in draught and a reduction in compaction problems?

A *Both tensile and compressive soil failure are useful when manipulating the soil. The usual problem with cultivations is that the operation is normally limited to soil conditions which are favourable for the tractor (good traction, low compaction). Roadways or gantry systems avoid this problem by divorcing the tractor and crop soil areas.*

Questions following Paper 2. (R Bellanger — Tractor hydraulics and implement control).

M J Dwyer (AFRC Engineering):

Q An electronic system which merely duplicates existing system design, misses the opportunity to provide the major benefits of sensing the horizontal component of draught force and the use of a single control. Sensing the horizontal force together with derivative control could substantially improve performance and eliminate the need for an intermix control. The aim should be to retain single lever control with electronics giving automatic operational adjustments.

A *In the commercial sphere progress has, in general, to be made in small steps, as large strides in technology often result in sales resistance. The present cost of equipment for measuring horizontal draught force makes its use impractical for commercial sales. Similarly, an electronic system with a single control would be too costly; in any case, once this system is set up, there is only one switch to operate on reaching the headland. The electronic system described in the paper is much better than a mechanical system because of the reduction in hysteresis.*

U C G Henniker-Wright (Retired from Ford Tractor Co):

Q Can the monitoring of wheel slip to control draught not be considered as a "work-dodger" in that undulating working depth results?

A *Wheel slip control carries out the same function as traditional draught control systems but faster and more efficiently.*

J Chambers (Retired from Massey Ferguson Ltd):

Q In a previous answer, Mr Bellanger inferred that his paper did not describe a large technological step in tractor/implement control. I disagree and wonder if farmers require such complicated and hence expensive control equipment?

A *The Ferguson hydraulic system is well designed and has been extended from use with 30hp tractors up to and over 80hp tractors. However, for these higher power tractors there is a need for more sophisticated and accurate control. This can only be achieved by the use of electronics.*

Questions following Paper 3 (P C H Miller — Spray application technology).

J C Jeffery (F W McConnel Ltd):

Q Does air-assisted spraying improve droplet penetration of the crop canopy and reduce spray drift?

A *There is limited information on the technique but the downward air current should reduce spray drift as it gives small droplets an increased velocity and should also improve penetration of the crop canopy. But if we blow air into the canopy will it also carry small droplets out of the canopy when reflected from the ground?*

J Young (P J Parmiter & Sons Ltd):

Q In Britain, £300 million, £300 million and £390 million are spent on tractors, combines and pesticides respectively. At this level of turnover, how much interest do chemical companies have in reducing the application rate of active ingredients?

A *Chemical companies are undoubtedly concerned with environmental aspects of their products but if rates of application were reduced, perhaps prices would be increased in order to maintain income?*

Questions following Paper 4. (W E Klinner — Innovations in harvesting equipment).

R J Godwin (Silsoe College):

Q What is the reaction of European/American tractor manufacturers to the idea of producing reverse drive mode tractors?

A *Manufacturers are reluctant to change the basic tractor concept due to the risks and costs involved. However, only modest costs need to be involved to convert the traditional tractor to the "system tractor" concept.*

There were no questions following Paper 5. (F E Goldsmith — Developments in milking machinery).

Engineering improvements for cowpea harvesting

E A Baryeh

Summary

FARMING in the developing countries is to a large extent unmechanised. This, together with other factors, accounts for their low agricultural productivity. Engineers can play a vital and leading role in alleviating this situation. In this respect, three types of manual harvesting of cowpeas have been studied and compared with two types of mechanical harvesting of upright, semi-upright and spreading cowpea varieties.

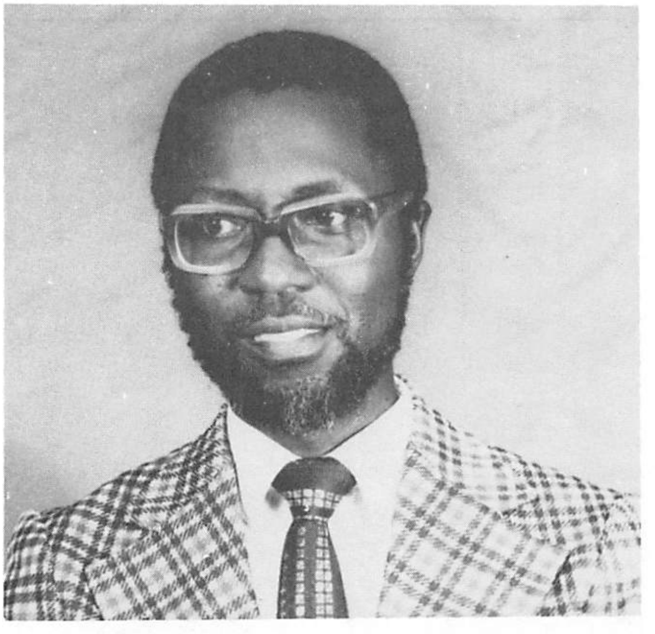
The results indicated that losses for manual harvesting varied from 0.5 to 16.9%, depending on the cowpea variety and type of manual harvesting. Losses from a cutter conveyor varied from 4.0 to 39.8% according to cowpea variety, moisture content and forward speed. Losses from a rotary cutter were between 11.6 and 41.5% for similar reasons. The average harvesting times for crop at 12% mcwb for manual harvesting, cutter conveyor and rotary cutter were 0.05, 0.17 and 0.10 ha/h respectively for the semi-upright variety. An economic appraisal of all the harvesting methods showed that manual shearing gave high crop losses and was slow to undertake compared with pod picking and uprooting. While both mechanized methods were much quicker than the manual harvesting, crop losses were excessive at crop moisture levels of 12% wb. At higher moisture levels of 28% wb, crop losses were considerably reduced but the dry matter yield loss of the crop was unacceptable. In general the rotary cutter had a better performance than the cutter conveyor. Recommendations are made for future work.

1 Introduction

Cowpea is one of the staple foods and vitamin sources in Africa (FAO 1980). In spite of this, cowpea harvesting, like the harvesting of other food crops in Africa is still unmechanised and therefore laborious and time and energy consuming. There is an obvious and urgent need for a suitable method of mechanically harvesting cowpeas to increase the farmers' output because harvesting time is second to weed control in limiting cowpea production.

This study of three types of manual harvesting and two power driven harvesters was conducted on mono-cropped cowpeas planted in rows and compared the energy expenditure, the time requirement and harvesting losses of the different techniques.

Dr Edward A Baryeh who is Deputy Managing Director of BEAG Farming and Haulage, PO Box 8049, Accra, Ghana, is currently on leave of absence at ENSIAAC, Ngaoundere, Cameroon. *Refereed paper submitted January 1986, accepted for publication March 1987.*



2 Manual harvesters and machine operators

Six young men, who were selected at random for the study, underwent a medical examination and were declared physically and mentally fit and their characteristics are given in table 1. They were tested on four occasions at six day intervals using the bicycle ergometer shown in fig 1. The men were used for manual harvesting and as machine operators for the mechanical harvesters.

3 Harvesting machines

The machines used were a modified production model cutter conveyor and a modified rotary cutter. The former, shown in fig 2, was a self-propelled machine with a 1m adjustable cutter bar, a 3.8 kW gasoline engine, an inclined rubber conveyor belt and a temporary cowpea hopper. It harvested two rows at a time. The modifications made to the machine were the inclusion of a second forward speed and the provision of a 1m diameter metal reel with rubber sheet overhanging the reel bars. In operation, the reel oriented cowpea stands towards the cutter bar for cutting and placement on the conveyor leading to the temporary storage hopper. Fig 3 shows crop flow through the machine.

The rotary cutter, shown in fig 4 consisted of a 0.3m diameter saw at one end of a 55mm diameter hollow aluminium shaft 1.5m long, a 1 kW gasoline engine at the other end of the shaft and handle in between these two components. The harvester was modified by providing a

Table 1 Characteristics of manual harvesters and machiner operators

Operative	*Age, years*	*Height, m*	*Weight, kg*	*Heart rate at rest, beat/min*	*Maximum heart rate beat/min*	*Oxygen consumption at rest, l/min*	*Maximum oxygen consumption, l/min*
A	25	1.65	65	65	190	0.250	14.5
B	28	1.75	72	64	198	0.242	14.9
C	30	1.70	70	63	195	0.242	14.6
D	25	1.66	68	66	186	0.255	14.0
E	27	1.80	75	65	200	0.253	15.0
F	26	1.58	64	60	188	0.232	14.0

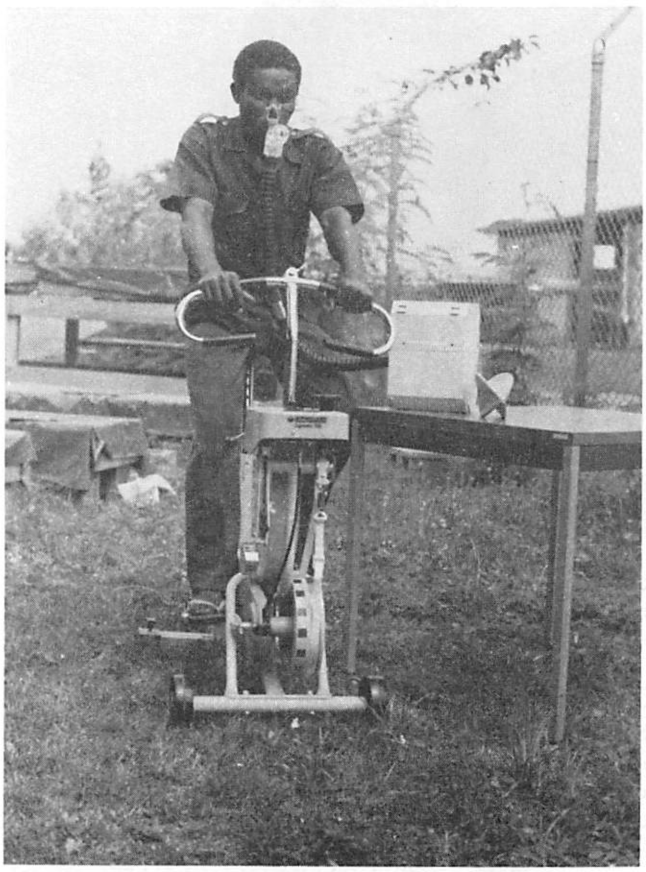


Fig 1 Bicycle ergometer

Fig 2 The cutter conveyor

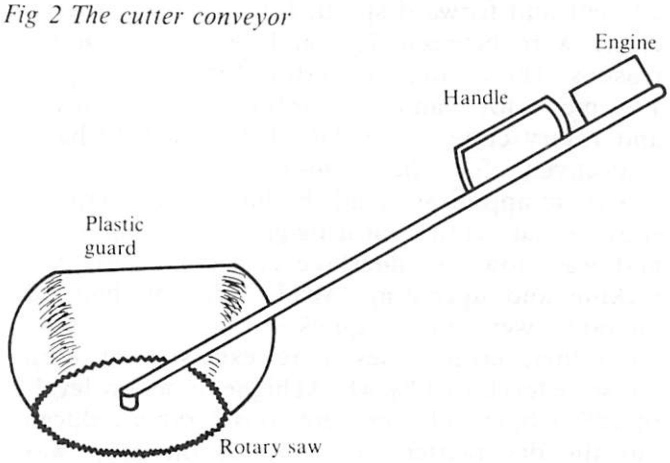
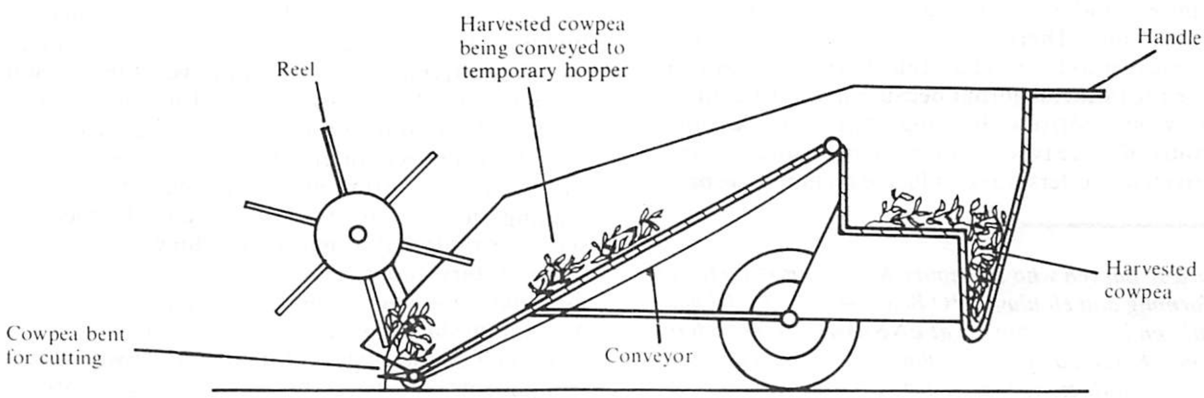


Fig 4 The rotary cutter

plastic guard behind the cutter to convey the harvested crop to the rear of the operator. In work the operator swung the shaft and saw assembly through an arc, as he walked between rows to cut the cowpea stands about 50mm above ground level to convey them to his rear. He traced his path, as he cut the next row, to cut adjacent rows into one windrow. The machine weighed about 15kg when filled with petrol.

Fig 3 The cutter conveyor showing crop flow



4 Experimental programme

The fields for growing the cowpeas were stump and stubble free, zero tilled with the crop grown on the flat. Fields were sprayed with glyphosate twelve days before planting; subsequent weed control being carried out manually. Good weed control resulted in a cleaner harvest and easier manoeuvrability of machines, hence good weed control is a prerequisite for use of the harvesters. Pesticides were also applied to ensure that insect damage by harvest time was negligible.

The tensile strength and the resistance to cutting of the cowpea stems were measured with a tensile testing machine, a band saw and a stopwatch. The tensile strength of straw was measured by equating the standing crop with a column having a side load as it was bent towards the cutter bar. The tensile strength affected the degree of bending which in turn affected the crop losses and hence net yield. Thus it was important to establish the tensile strengths of the stems of the different cowpea varieties harvested. The resistance to cutting was based on the time taken to cut through 10mm diameter stem with the band saw. This parameter was investigated to assess whether the stem strength characteristics of the cowpea varieties harvested differed sufficiently to effect harvester performance and hence warrant the need for adjustment of the results to obtain comparative data.

Fields, cultivated at 750mm row spacing with three cowpea varieties were divided into 150m^2 treatment plots with five replications of each using a randomised complete block statistical design.

Upright, semi-upright and spreading cowpea varieties were harvested by the six men on the plots at the normal moisture content of 12% wb using the following manual harvesting methods:

(i) pod picking followed by threshing,
(ii) uprooting followed by threshing,
(iii) shearing followed by threshing.

This was repeated for a harvesting moisture content of 28% wb to investigate the effect of cutting earlier and of drying. Harvesting is normally done by the young and old and by male and female. Young men were used for the investigation because they were the most willing and reliable. The harvesting time, yield, losses, heart rate, oxygen consumption, threshing losses and damage were measured. Heartbeat rate was measured by palpating the wrist and counting for 20 seconds using a stopwatch for timing. Oxygen consumption was measured directly by the gas sampler and analyser shown in fig 5. This was also estimated directly based on variation in the heart rate (Murrell 1971).

The men operated the two harvesting machines on similar plots. In addition to the parameters mentioned for normal harvesting the fuel consumption of the machines was measured. Two speeds of 1.5 and 2.5 km/h were used for crops harvested at 12% moisture content and one speed of 4.0 km/h for crops of 28% moisture content.

5 Results and comments

The average tensile strength of the stems was 1750 N/m^2 for all the cowpea varieties while the average time for cutting a 10mm diameter stem was 2.5 seconds at 12% moisture content. The corresponding values for 28% moisture content was 1650 N/m^2 and 3.0 seconds respectively. The results from the measurements of the strength and resistance to cutting of the stems were not dissimilar for all cowpea varieties, hence no corrections of

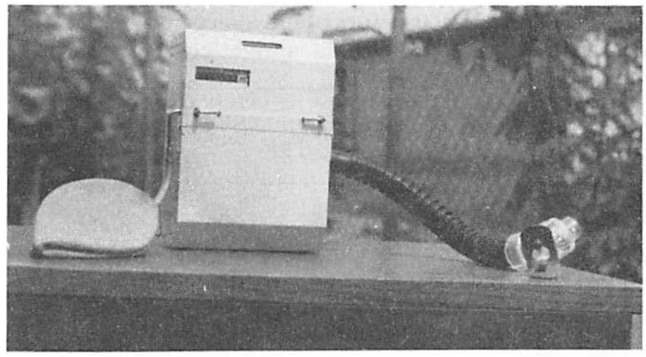
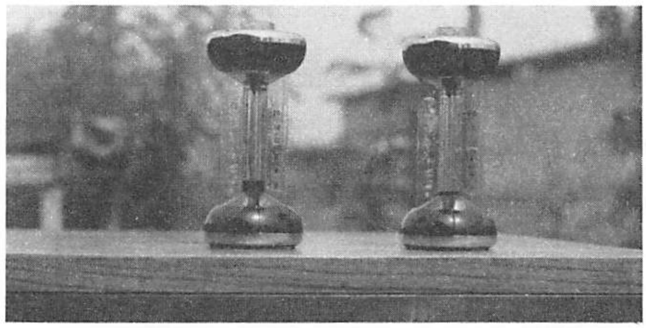


Fig 5 (a) Gas sampler
(b) Gas analyser



performance data were required for harvesting different varieties.

5.1 Harvesting crops at 12% moisture content wb

The average peak heartbeat, the time taken to reach this peak and the pulse recovery time for the upright variety are displayed graphically in fig 6. The corresponding oxygen consumption and energy expenditure are shown in table 2. As the operators were of similar age and weight, the average energy expenditure was not recorded as

Fig 6 Mean heartbeat rate of operators when undertaking:
A - Rotary cutting
B - Cutter conveying at 2.5 km/h
C - Uprooting
D - Pod picking
E - Cutter conveying at 1.5 km/h
F - Shearing

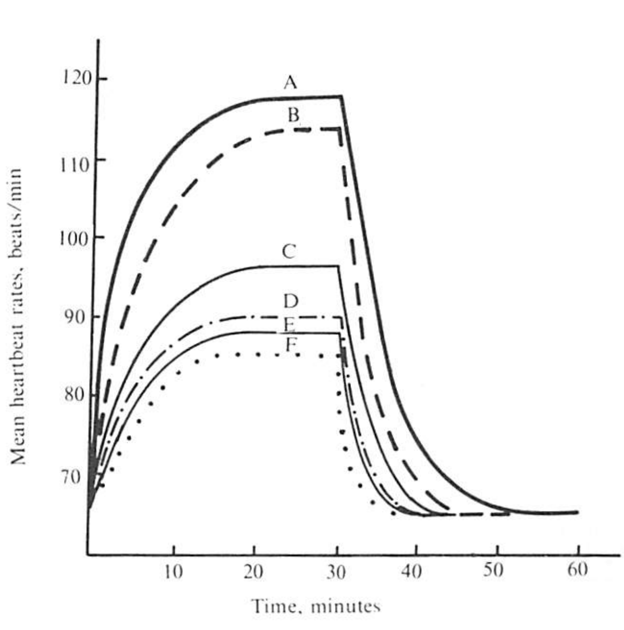


Table 2 Oxygen consumption and energy expenditure of operatives when harvesting the upright cowpea variety

Harvesting method	*Oxygen consumption, l/min*	*Energy expenditure, kJ/min*
Rotary cutter	1.30	27.20
Cutter conveyor at 2.5 km/h	1.24	25.94
Uprooting	0.92	19.25
Pod picking	0.80	16.74
Cutter conveyor at 1.5 km/h	0.76	15.90
Shearing	0.70	14.64

energy per unit of body weight. The data for the other varieties were similar, although the results for the rotary cutter and shearing were about 7.5 and 5.0% higher respectively for spreading varieties and 5.0 and 2.5% higher respectively for semi-upright varieties. These small differences were due to the extra energy required to work the rotary cutter and the shears underneath the plant canopy to cut the stem. The graphs indicate that the operator of the rotary cutter had the greatest heart rate of 118 beats/min corresponding to an energy expenditure of 27.2 kJ/min. This was followed by operators working on or at the cutter conveyor at 2.5 km/h, uprooting, pod picking, the cutter conveyor at 1.5 km/h and shearing. The pulse recovery times followed a similar pattern. The operator of the rotary cutter has the highest pulse recovery time of 20 minutes while the one shearing had the lowest of 10 minutes with the others falling between these two values. Results for the rotary cutter were for an average walking speed of 3 km/h. Walking at this speed, an average man had an energy expenditure of about 16.7 kJ/min (Murrell, 1971) but due to the swinging of the machine the operator's energy consumption increased to 27.2 kJ/min. Energy expenditure for the cutter conveyor obviously depends on the speed of operation and the effort put into turning the machine and occasionally emptying the temporary hopper. Thus at the working speed of 2.5 km/h, the operator expended 10.0 kJ/min of energy more than at the lower speed of 1.5 km/h. At 4.0 km/h, the energy expenditure was 39.3 kJ/min.

The work rate could be maintained for about five or six hours continuously using the machines while work rates for manual harvesting could be maintained for about two hours because this latter type of work caused backache, so workers took frequent rests although the energy expenditure while working was sometimes much lower than when machine harvesting.

Among the manual harvesting activities, uprooting required the highest energy. The energy requirement varied with the degree of soil compaction but this parameter was not examined in detail. Most of the stems left from harvesting by other methods were usually rotted before the next crop. Any that were not rotted were uprooted during land preparation for the next crop. Uprooting therefore simplified cultivation for the subsequent crop as well as improving soil aeration and rainfall infiltration.

Shearing required the lowest energy consumption because the operator took some time to cut the stem whereas more body movements occurred with the other methods.

Table 3 Results for the various harvesting methods for the crop varieties at 12% moisture content

Harvesting method	*Cowpea variety*	*Total yield, kg/ha*	*Shatter loss, kg/ha*	*Field losses, kg/ha*	*Total losses, kg/ha*	*Total losses, %*	*Harvesting rate, ha/h*	*Net yield, kg/ha*
Pod picking	Upright	2220	10.0	7	17.0	0.8	0.067c	2198a
	Semi-upright	1990	10.5	9	19.5	1.0	0.065c	1916a
	Spreading	1905	8.6	15	23.6	1.2	0.057c	1875a
Uprooting	Upright	2000	8.4	10	18.4	0.9	0.063c	1975a
	Semi-upright	1800	8.2	15	23.2	1.3	0.056cd	1770b
	Spreading	1880	7.1	35	42.1	2.2	0.050d	1830a
Shearing	Upright	1895	7.5	104	111.5	5.9	0.032e	1776b
	Semi-upright	1800	9.3	177	186.3	10.4	0.029ef	1608b
	Spreading	1500	8.7	220	228.7	15.3	0.025f	1265c
Cutter conveyor (1.5 km/h)	Upright	1985	122.5	63	185.0	9.3	0.095b	1785b
	Semi-upright	1898	180.0	170	350.0	18.4	0.091b	1533b
	Spreading	1606	113.0	329	442.0	27.5	0.095b	1149c
Cutter conveyor (2.5 km/h)	Upright	1906	250.0	102	352.0	18.5	0.182a	1539b
	Semi-upright	1795	266.0	145	411.0	22.9	0.175a	1365c
	Spreading	1587	234.0	398	632.0	39.8	0.175a	940
Rotary cutter (3.0 km/h)	Upright	1906	153.0	44	197.0	10.3	0.111b	1694b
	Semi-upright	1884	165.0	55	220.0	11.7	0.100b	1649b
	Spreading	1606	227.0	233	460.0	28.6	0.071c	1146c

Means with common letters are not significantly different at $P < 0.05$ by Duncan's Multiple Range Test.

The average fuel consumptions for the cutter conveyor were 10.1 and 5.4 litres/ha at 1.5 km/h and 2.5 km/h respectively while that for the rotary cutter was 6.8 litres/ha. Thus at 1.5 km/h, the cutter conveyor used more fuel per hectare than the rotary cutter while at 2.5 km/h, it used less.

The mean values of the yield, losses and harvesting rate are displayed in table 3 for 12% moisture content. The total yield was greatest for the upright variety followed by the semi-upright and lowest for the spreading variety.

All the manual harvesting methods had low shatter losses. The shatter losses from the cutter conveyor were highest with semi-upright varieties followed by spreading and then upright varieties at 1.5 and 2.5 km/h. The cutter bar missed some of the pods of the spreading variety and consequently harvested proportionately fewer pods; which explains the higher shatter losses for the upright and semi-upright varieties. Table 3 indicates that there was a positive correlation between the speed of operation and the shatter losses. These losses were 6.2, 9.5 and 7.0% for the upright, semi-upright and spreading varieties at 1.5 km/h. The corresponding values for 2.5 km/h were 13.1, 14.8 and 14.7%. The increase in forward speed generally more than doubled the shatter losses for the upright and spreading varieties.

When harvesting with the rotary cutter, the shatter loss was highest from the spreading variety. This was due to the cutting head fouling pods as the operator searched for the plant stem with the machine. These losses were 14.1, 8.8 and 8.0% for spreading, semi-upright and upright respectively. The worst shatter loss occurred from the cutter conveyor at 2.5 km/h harvesting the spreading variety, followed by the rotary cutter harvesting the same variety.

Field losses were generally low for pod picking and uprooting from all varieties; the losses varied from 0.3 to 1.9%. Shearing losses of 5.5 to 14.7% were recorded, these were attributed mostly to stems that the operator could not shear due to their dryness and their toughness. Field losses were highest from the spreading variety in both types of machine harvesting, followed by semi-upright and upright, the greatest losses were mostly due to pods missed by machines when harvesting the spreading variety. These losses were 3.2, 9.0 and 20.5% from upright, semi-upright and spreading varieties harvested by the cutter conveyor at 1.5 km/h and 5.4, 8.1 and 25.1% at 2.5 km/h; the corresponding values from the rotary cutter at 3.0 km/h were 2.3, 2.9 and 14.5%. The greatest losses were again from the cutter conveyor at 2.5 km/h harvesting a spreading variety followed by the rotary cutter harvesting the same variety.

The threshing losses averaged 15 kg/ha from all harvesting methods, the same sheller being used for all treatments. The threshed peas from uprooting, shearing and machine harvesting had a considerable amount of trash which the cleaning fan of the sheller did not remove. The final product from pod picking was the cleanest. At present, the trash content of the threshed crop does not affect its marketability partly because there is insufficient crop available and partly because most villagers are willing to buy a 'dirty' crop and carry out further cleaning before consumption. The trash was not likely to adversely effect safe storage of cowpeas because it was as dry and in some cases dryer than the crop. Further cleaning was not likely to create another labour bottle-neck because the time required for such cleaning would be much less than the time saved in mechanised harvesting. Moreover, such cleaning could be done during periods of farm labour demand.

The total crop losses were unacceptably high from the cutter conveyor and rotary cutter machines, particularly when harvesting the spreading variety. These results were 27.5% at 1.5 km/h and 39.8% at 2.5 km/h for the cutter conveyor, and 28.6% for the rotary cutter. Total losses from the upright and semi-upright varieties using the cutter conveyor at 2.5 km/h were 18.5 and 22.9% respectively, which were also unacceptable. The remaining total losses were all less than 18.5%.

The harvesting rate was, in general, low for manual harvesting, ranging from 0.02 to 0.07 ha/h depending on the type of harvesting and the type of cowpea variety. Machine harvesting on the other hand ranged from 0.07 to 0.18 ha/h. Uprooting generally took longer than pod picking, while shearing took the longest time of the manual harvesting methods. As expected, the cutter conveyor had the best harvesting rates at 2.5 km/h but it caused the highest crop losses and consequently returned the worst net yield. Manual harvesting had a high net yield but was time consuming. The manual harvesters complained that uprooting and shearing caused backache. Operators also found that extended use of the rotary cutter was tiring.

5.2 Harvesting crops at 28% moisture content wb

The results are shown in table 4. The average peak heartbeat rate, oxygen consumption and energy expenditure in manual harvesting and rotary cutter operations for this part of the investigation were not significantly different from those for 12% moisture content. The values for operators of the cutter conveyor were 132.0 beats/min, 2.2 litres/min and 39.33 kJ/min respectively. All these values increased because the machine was operated at a high forward speed of 4.0 km/h. At this speed, high losses of 32.0, 44.2 and 75.4% from harvesting the upright, semi-upright and spreading varieties had made the machine totally unsuitable for harvesting the crop at 12% moisture content.

At 28% moisture content, the manual harvesting methods had practically zero shatter losses, but the field losses were higher for pod picking and uprooting. As a result, the proportion of losses did not vary much between the two moisture content levels at harvest.

The table indicates that the high moisture content resulted in greatly reduced shatter and field losses down to about a third and two thirds respectively of the values at 12% moisture content because the pods did not split open so easily and had a lower resistance to cutting. Pods harvested at this moisture content, however, had to be dried before threshing; in the tropics sun drying was normally adequate for this purpose. The reductions in the shatter and field losses were reflected in significantly lower total losses. The proportional losses for the manual harvesting methods did not differ significantly from the two crop moisture contents. The reduction in losses from the machine harvesting was very marked when harvesting a crop with a cowpea moisture content of 28% rather than one of 12%. For example, the spreading variety in the drier crop had the highest loss of 39.8% which dropped to 12.9% in the wetter crop. Similarly the upright variety dropped from 9.3 and 18.5% loss at 1.5 and 2.5 km/h respectively to 4.0% when harvested at 28% moisture content and at 4 km/h. The rotary cutter dropped from 10.3 to 4.0%, 11.7 to 4.8% and 28.6 to 11.4% loss for the upright, semi-upright and spreading varieties.

Table 4 Results for the various harvesting methods for the cowpea varieties at 28% moisture content

Harvesting method	*Cowpea variety*	*Total yield, kg/ha*	*Shatter loss, kg/ha*	*Field losses, kg/ha*	*Total losses, kg/ha*	*Total losses, %*	*Harvesting rate, ha/h*	*Net yield, kg/ha*
Pod picking	Upright	2000	—	10.0	10.0	0.5	0.050c	1975a
	Semi-upright	2117	—	10.5	10.5	0.5	0.039c	2092a
	Spreading	1984	—	20.5	20.5	1.0	0.033d	1949a
Uprooting	Upright	1987	—	20.4	20.4	1.0	0.44c	1952a
	Semi-upright	2002	—	25.5	25.5	1.3	0.028d	1962a
	Spreading	1890	—	47.6	47.6	2.5	0.026de	1827a
Shearing	Upright	1900	—	98.8	98.8	5.2	0.028d	1786ab
	Semi-upright	1900	—	165.5	165.5	8.7	0.022ef	1720b
	Spreading	2077	—	350.0	350.0	16.9	0.019f	1734b
Cutter conveyor (4.0 km/h)	Upright	2020	38.4	42.0	80.4	4.0	0.333a	1903a
	Semi-upright	2055	62.6	110.1	172.7	8.4	0.323a	1840a
	Spreading	1880	40.1	202.3	242.4	12.9	0.357a	1608c
Rotary cutter (3.0 km/h)	Upright	1994	52.0	28.5	80.5	4.0	0.122b	1877a
	Semi-upright	1896	55.5	35.2	90.7	4.8	0.118b	1775b
	Spreading	2008	77.7	150.4	228.1	11.4	0.098b	1747b

Means with common letters are not significantly different at P 0.05 by Duncan's Multiple Range Test

Harvesting rate for the manual techniques decreased when it was carried out at 28% bean moisture content, the rates ranging from 0.02 to 0.05 ha/h. On the other hand, the cutter conveyor produced a much greater harvesting rate varying between 0.33 and 0.35 ha/h while the harvesting rate of the rotary cutter did not change significantly. Although the mean total yield of crop at 28% mc wb was 139 kg/ha greater than that from crop at 12% mc wb, once dry matter yields were calculated, the values were 1621 kg/ha dm yield for the 12% mc wb crops and 1426 kg/ha per the 28% mc wb crops. The difference between the two crops of 195 kg/ha (SE = 37.6) was statistically significant ($P > 0.01$).

6 Discussion of results

The physical labour and time consumption for manual harvesting is unacceptable if the African continent is to produce enough cowpea to feed itself and for possible future export. The results generally indicate a high yield loss from the spreading variety, especially with machine harvesting; therefore, it is suggested that this variety is unsuitable for mechanised harvesting. The cutter conveyor at the lower forward speed and the rotary cutter both produce reasonably high harvesting rates. The energy expended by the operator of the latter machine is high but it is within reasonable limits and the fuel consumption is low for both machines.

In order to assess the economic viability of the different harvesting methods, the costs of the three manual and two machine harvesting treatments are shown in tables 5 and 6, at crop moisture content of 12% in the former and 28% in the latter table.

Costs of harvesting include the value of total crop losses based on a price of 36p/kg for a 12% mc crop and at 0.30 p/kg for a 28% mc crop to take into account the lower yield of dry matter in the latter crop (these figures have been calculated from the semi-upright variety yields only). The labour cost at harvest is based on a charge of £200/ha working at 0.03 ha/h. The actual charges made for each treatment have been calculated as a proportion of the above labour cost in the same relationship that the

Table 5 Harvesting costs for semi-upright crop at 12% mc wb

Harvesting method	*Crop losses, kg/ha*	*Value of losses at 35p/kg, £/ha*	*Labour costs, £/ha*	*Total cost, £/ha*
Pod picking	19.5	7.02	92	99
Uprooting	23.2	8.35	107	115
Shearing	186.3	67.07	207	274
Conveyor cutter @1.5 km/h	350.0	126.00	68*	194
Conveyor cutter @2.5 km/h	411.0	147.96	37*	185
Rotary cutter @3.0 km/h	220.0	79.20	61+	140

**Includes £3/ha for fuel & repairs*
+ Includes £1/ha for fuel & repairs
N B For full explanation of headings for tables 5 & 6, see text under "Discussion of Results".

Table 6 Harvesting costs for semi-upright crop at 28% mc wb

Harvesting method	*Crop losses, kg/ha*	*Value of losses at 30p/kg, £/ha*	*Labour costs, £/ha*	*Value of dry matter yield loss, £/ha*	*Total cost, £/ha*
Pod picking	10.0	3.00	154	119	276
Uprooting	25.9	7.77	214	118	340
Shearing	173.5	52.05	273	109	434
Cutter conveyor @ 4 km/h	167.5	50.25	22*	110	182
Rotary cutter @3 km/h	95.7	28.71	52+	114	195

**Includes £3/ha for fuel & repairs*
+ Includes £1/ha for fuel & repairs

recorded work rate has to the standard rate of 0.03 ha/h. The costs of fuel for the conveyor cutter and the rotary cutter have been included at £2.00/ha and £0.75/ha respectively. Repair costs are estimated for the same two machines at £1.00/ha and £0.25/ha respectively. The final column is a total of all costs.

In table 6, there is an additional column in which the cost of crop dry matter losses due to harvesting at 28% mc is recorded. These have been calculated from the yield of all the high level moisture content plots. The individual treatment yields have had deductions at the rate of 6p/kg (36p – 30p/kg) as a loss in value from the harvested yields compared with those from the crops harvested at 12%.

From this economic assessment, it can be seen that the reduction of crop losses by harvesting at a higher moisture content is offset by the higher loss of dry matter yield values, which is between £109 – £119/ha from all treatments. Only the cutter conveyor benefits costwise by harvesting at high moisture contents. Although both mechanical treatments cost less than the manual treatments in the high moisture level crop, through a large reduction in crop losses, there is no doubt that better returns are obtained by harvesting at the normal crop moisture level of 12%.

At both crop moisture content levels, there are striking differences between manual harvesting rates. Pod picking was the lowest in cost due to the comparatively high work rate for manual harvesting, coupled with the lowest level of crop loss. Similarly uprooting plants was nearly as good in both these same respects. These two manual treatments were more cost effective than the two mechanical treatments in the 12% mc crop although the work rate was not comparable to mechanised methods. Hand shearing was the most expensive of all at both crop moisture levels due to a combination of low work rates and fairly high crop losses. The rotary cutter was the least costly of the two mechanised harvesting methods in the drier crop due to lower crop losses than for the cutter conveyor. This latter machine had the fastest working rate. In the crop with the high moisture level, the rotary cutter had a much lower rate which resulted in this treatment being the most costly mechanical method of harvesting.

7 Conclusions

The study has compared manual harvesting and two mechanical harvesting methods. Energy expended by operators and manual workers has been evaluated and compared. Crop losses has been found to be unacceptable for the spreading cowpea variety. Manual harvesting except for shearing, has low losses but all these methods are laborious and time consuming, which makes the harvesting window small and leaves little time for tillage and sowing of the next crop. The result of this can be an unnecessary proportion of land left fallow.

The use of mechanical harvesters such as the rotary cutter can overcome the timeliness problem but results in high crop losses unless harvesting is undertaken at much higher moisture levels (28% wb). However, such a technique imposes a severe penalty by reducing the dry matter yield of the crop.

In order for mechanised harvesting to be viable, there is a need for: (a) further development work on the machines to reduce the level of crop loss on drier crops; and (b) further trials at crop moisture levels of between 12 and 28% wb to determine if an immediate moisture value will provide the reduction of crop loss required without the same penalty of high dry matter yield loss.

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Book review
Introduction to agricultural mechanisation
R N Kaul and C O Egbo

Publisher: Macmillan, London, 1985. ISBN 0-333-39148-9. £6.95.

THIS book provides an introduction to most aspects of agricultural mechanisation. Section A (57 pages) discusses the main sources of farm power with especial reference to internal combustion engines. Section B describes a wide variety of farm machines for tilling, planting, harvesting, irrigating and other operations as well as short chapters on cost analysis and materials. Considering the range of machinery covered and the number of different operations that need to be carried out in tropical agriculture, the fact that everything has been included in under 200 pages is no mean achievement. This book should enable students approaching the subject for the first time to obtain a firm grounding in the theory and principles governing farm machinery.

The style of writing is simple and generally easy to follow. However, occasionally some explanations are confusing such as those of hydraulic control systems (section 9.4) and engine performance graphs (10.2).

The book is copiously illustrated both with photographs and diagrams. The latter in particular are very useful in helping the reader to understand how mechanisms work.

There are a few lapses from the generally high standard of presentation. The text does not match the illustration in section 1.2.2/fig 1.1b. In fig 22.6 a spiral auger is shown rotating in the wrong direction and fig 4.10, the governor mechanism on a tractor apparently increases the fuel supply the faster the engine goes! Appendix A informs us that 1 mile = 1.61kg and 1 cubic inch = 16.39cm^2 (sic).

Apart from these minor and specific criticisms one is also left with a nagging feeling that, like most introductory texts, this book does not take enough account of the real world in which, presumably, the majority of students reading it will eventually be working. In short, the book says much about how machines ought to work but virtually nothing about what to do when they do not. I feel that the book would be even more useful and credible if section 10 on the preventive maintenance of engines were expanded and extra sections included on the diagnosis and treatment on the common ailments of electrical and hydraulic systems. Also useful would be a chapter on the techniques available for joining broken metal components including welding, brazing and riveting. Finally, a few words about how to make simple bushings and gaskets would be a great help especially to people working in countries where off-the-shelf spare parts may not always be available.

P R Lawrence

RASE publishes user experience reports

W E Klinner

1. The RASE Machinery Award Scheme

UNDER the guidance of the previous Honorary Consulting Engineer to the Royal Agricultural Society of England, Mr Claude Culpin OBE, a Fellow and Past-president of the Institution, the Machinery Award Scheme sponsored and run by the Society, has progressed and now offers farm equipment manufacturers a reliable method of evaluating their products. Eligible for entry are all types of field and barn machinery, dairy and horticultural equipment, management and operational aids, etc. Normally at least six units must be in use on British farms and, ideally, the entries should represent the latest state of development.

Assessment of suitability of entries for use in British agriculture is made by a panel of 10 judges who visit users to learn first-hand of their experience. Reports written on each such visit are circulated to all judges and twice a year the full panel meets to decide what awards are appropriate. The meetings are timed so that the results are available prior to the Royal Smithfield Show in December and the Royal Show in July. Entrants are free to use the outcome of the assessment procedure for publicity purposes.

Three levels of RASE Machinery Award may be given:

- An Award of Merit, which signifies that a machine or item of equipment has been found to be reliable by users in terms of its performance and function, and that it should be included by a potential buyer in his list of possible purchases.
- A Silver Medal, which implies similar findings, but, additionally, that the project has important new features or outstanding advantages of benefit to users.
- One Gold Medal may be awarded annually at the Society's discretion to the best entry which meets the criteria for a Silver Medal and has special new features and advantages likely to contribute to substantial progress in its field of application.

The assessment process starts with the judges being thoroughly briefed on each entry by its manufacturer or marketing company.

2. RASE User Experience Reports

The thoroughness of the enquiry procedure, of which the judges' reports are a vital aspect, results in much important information being collected, but in the past no further use was made of it subsequently. This seemed wasteful when so little unbiased help is available to farmers in their decision making for machinery purchases. Moreover, manufacturers in the UK had lost the opportunity many years ago of having the performances of their products tested by an independent agency and of using the results of test for publicity purposes.

It was for these reasons that, after discussions with representative organisations, it was decided to extend the Machinery Award Scheme by offering entrants the option of commissioning written reports based on the judges' findings.

Depending on the entrant's need, he may order one of two types of report.

Option 1. Reports are strictly confidential and draw attention to all aspects of design and construction which adversely affect performance, reliability, durability and economy of use. Recommendations are made for improvements and, if these are followed up with appropriate modifications, a better product should result to the benefit of the manufacturer and his customers.

Option 2. Reports cover every aspect of the survey, including details of the sample farms, performance information, user assessment, judges' conclusions and recommendations. The section on performance information details findings on such aspects as work rates, quality of work, ease of operation, maintenance and service, economy of use, suitability of design and construction and safety. Where necessary, recommendations are made for improvements and the entrant is given the opportunity to add comments relating to the recommendations.

Publication of the Option 2 Reports is voluntary, and they are written and laid out in such a way that a two-sided abridgement can be separately published without further reference to the RASE, which holds the copyright. Distribution of the reports is at the discretion of sponsors, and the Society offers the additional facility of full or selective mail shots.

The first User Experience Report shown in fig. 1 was published in the Spring of 1987 and was on the Claas Rollatex Net Wrapping Attachment for Claas Rollant 44 and 62 Round Balers. Entrants were J Mann and Son Ltd, of Bury St Edmunds, who welcomed the opportunity to actually see and use the results of the judges' work. They found the document invaluable both in terms of an independent assessment and as a marketing tool for one of their advanced products.

In extending its Machinery Award Scheme to provide valuable feed-back to agricultural equipment manufacturers and concessionaires and guidance to farmers on the effectiveness of new equipment, the RASE is moving with the times and responding to the needs of the industries it serves.

Wilf Klinner recently retired from the post of Divisional Head at AFRC Engineering, Silsoe. He is now Honorary Consulting Engineer for the RASE.

THE ROYAL AGRICULTURAL SOCIETY OF ENGLAND

RASE

RASE Machinery Award Scheme

Report No. 87 001S

Fig 1 Cover of the first User Experience Report