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A new design concept for combine harvesters

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Front cover:
A new stripping header developed for combine harvesters by AFRC Engineering (Photo: AFRC Engineering)

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Contents

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Guest editorial
Combines and straw

Harry J Nation

FOR some years no combines have been manufactured in the UK but those offered for sale to the farmer have incorporated several new features, developed either in mainland Europe or in North America. The appropriateness of some of these developments for harvesting in temperate regions, and in the face of the general down-turn in combine sales, has yet to be proven. In the light of these factors and recent research and development in this country, the South-east Midlands Branch organised a one day conference on 10 September 1986 at Silsoe College, widened in scope to include treatment and utilisation of straw and to complement the BSRAE Members' Day on Cereals and Straw at the AFRC Institute of Engineering, Wrest Park on the following day.

The conference attracted an attendance of 144 and was chaired by the Hon Oliver Walston, who farms some 3000 acres in Cambridgeshire, mostly cereals which he harvests with the latest combines and without burning the straw. The conference programme covered combine design in the morning and straw utilisation in the afternoon. The papers on combines moved from reviews of the present situation and recent developments to the final one on a radical new harvesting process by the inclusion of which the conference might make some contribution towards a return to manufacture in this country.

The general scene of the "Combine Business" was outlined by Alec Williamson from New Holland (now part of Ford New Holland Ltd) at Aylesbury who, after a brief historical review, dealt with the market place and the factors which affect it. He referred to the continuing trend towards larger machines and the need for these to deal with a greater variety of crops. The quality of in-field, back-up service and facilities for operator training are assuming greater importance in the choice of combine make.

Recent developments in combine design, including the different, new varieties of threshing systems, means for improved performance on hillsides and for better operator working conditions were reviewed by, Hermann Garbers from Claas in Germany.

FiatAgri represent its wholly-owned subsidiary, Laverda in the UK and Philip Bosworth described the new front-mounted threshing and separating mechanism introduced by the Italian company on the MX 240 transverse rotary drum combine. He described how the machine consists of three functional groups of mechanisms — the header, the thresher-separator carried on the table and the main frame with grain tank and power unit.

The morning session concluded with an account by Wilf Klinner of the development and performance of the stripping header at AFRC Engineering and now under commercial evaluation by a UK company, Shelbourne-Reynolds.

Whilst these recent, radical developments featured largely in the discussion, concern was also expressed that present-day combines did not show developments aimed at improving the ability to deal with those crops which appear to present more difficulty in combining but which will become more important as farmers turn to alternatives to conventional cereals.

With the exception of the paper by Hermann Garbers which was reproduced in the 1986 Winter issue (Vol 41, No, 4) of the Journal, these papers from the morning session are to be found in the following pages of this current Journal.

The afternoon session started with a comprehensive review of all the uses for straw, given by Arthur Staniforth, who during his days in ADAS specialised in this subject and organised the regular conferences on straw at Oxford for several years. Included was the mention of straw as a fuel; but as a widespread alternative to fossil fuels the adoption of straw is limited by its relatively low calorific value and low density. High density baling and briquetting provide a partial solution to the transport and storage problems. Most of the other uses described can account for only a very minor proportion of the large amount of surplus straw.

The ADAS and AFRC Engineering survey and research on straw chopping were reviewed by Harry Gilbertson in a joint paper with Andrew Knight, both of AFRC Engineering and indications were given that developments are likely which will lead to reduced power

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Harry Nation is Chairman, South-east Midlands Branch of the Institution. He retired from NIAE (now AFRC Engineering) in April 1986, after a final two years working on the straw wafering project, mentioned above. Previously, he had spent some 18 years on crop protection machinery and techniques and before that had been concerned with other aspects of agricultural engineering research.

consumption. It is believed that with combine mounted choppers, output can be limited by the significant power requirement of the chopper. Uniformity of distribution of chopped straw has also been studied showing that improvements are required both for effective incorporation and for efficient burning but wind conditions can have an uncontrollable influence.

Two other papers dealt with packaging of the straw for transport. One reviewed bale and baler types and sizes and methods for dealing with bales in groups or unit loads for transport and was given by Don Bull of ADAS at Silsoe. The other paper described research work on high density baling and very high density wafering of straw, given by Mike Neale of AFRC Engineering. These last three papers were reproduced in the 1986 Winter issue of the Journal.

Associated with the conference, the organisers had invited manufacturers and organisations to bring display boards to publicise their work or products. About a dozen displays were erected and visited by delegates for informal discussions during the refreshment breaks.

Manufacturers accounted for about one-third of the attendance, another third came from the research, advisory and education sectors including students and the remainder consisted of farmers, contractors, merchants, consultants, press and dealers.

Convenors for the conference were Robin Lewis of Silsoe College and Don Bull of ADAS Liaison Unit at AFRC Engineering.

A battery powered skid-steer loader, the "Skidtric"

R Alcock

Summary

A BATTERY powered skid-steer loader (the "Skidtric") that can be used for materials handling, excavating, and in-building tasks was designed and constructed. This vehicle is seen as being particularly applicable for those industries currently using skid-steer loaders such as agriculture, and the building industry. It offers advantages, when compared to skid-steers of comparable size powered by internal combustion engines, of lower noise levels, negligible emissions and reduced operating costs.

The Skidtric has the added unique feature (for skid-steer loaders) of side entry. The inclusion of this design feature has not limited the operating characteristics of this vehicle. The lift height, reach and rated load are all comparable with equivalent sized skid-steer loaders.

Introduction

Farmers in the Mid-west find two quite separate uses for agricultural tractors. The first category involves field work, with ploughing or deep cultivating being those activities responsible for the major power demand. Tractors used for these operations typically have rated power levels which vary with farm size. Resen, *et al* (1980) found that small (<80 ha) farms had one tractor with a rated drawbar power of 45 to 52 kW. Farms in the 80 to 400 ha size range had tractors of between 75 to 82 kW. Large (> 400 ha) farms employed tractors in the 123 to 130 kW drawbar power range. The second major use of agricultural tractors is for utility work such as snow clearing, yard clearing, cattle feeding, and daily farm "chore" routines. Resen, *et al* (1980) found that the size of this utility tractor was similar for all three ranges of farm size. This tractor was usually in the 20 to 40 pto kW size range and was almost always equipped with a front-end loader.

It was proposed that the utility tractor could well be powered electrically using on-board battery packs and dc motors for traction and hydraulics. There are, it is thought, several advantages to this approach. The utility tractor is quite often used near livestock and required to move in and out of farm buildings. The inherent battery powered vehicle characteristics of low noise and negligible emissions make them eminently suited to such activities.

The first battery powered tractor built in the Agricultural Engineering Department of South Dakota State University was described in an earlier paper in this journal (Alcock and Christianson 1985). This was a four wheel drive, loader equipped, tractor with an articulated frame steering system. Although this vehicle performed effectively when used as a utility tractor, its overall dimensions precluded its general use for in-building work. In view of this limitation, a second, smaller vehicle, was proposed. This second battery powered vehicle, designed and built at the Agricultural Engineering Department of South Dakota State University, was a skid-steer loader (the "Skidtric"), and is the subject of this paper. The skid-steer design was chosen because of the current popularity of these vehicles throughout North America for farm and industrial use.

Skid-steer loaders are used quite extensively by farmers in the Mid-west, and in other parts of the United States, for hauling feed, scraping yards and cleaning dairy barns. They have also found use in the building industry, for clearing materials and excavating foundations. A common characteristic is that they tend to be used intermittently and are occasionally used for short duration heavy duty applications such as clearing a large rock and breaking out compacted materials from a pile. These operational requirements are suited to the characteristics of battery powered vehicles. The intermittent requirement effectively extends the operational time, and the series wound motors used for traction have a rising torque characteristic which enables them to cope with short duration overloads.

Battery powered vehicles offer advantages in terms of savings in energy and repair costs. Energy savings in the range 57 to 76% were obtained when two similar vehicles, battery and diesel powered respectively, were compared in performing similar tasks (Vik 1985). This was obtained assuming diesel fuel costs of $0.26 per litre and electricity costs of $0.05 per kWh. Energy consumption was determined from measurements of fuel consumption in the case of the diesel vehicle, and from a kilowatt-hour meter that recorded the energy output from the battery during use of the battery powered vehicle. Similar energy savings were obtained by Elamin (1981) in comparing the performance of battery and petroleum powered lawn garden tractors. Steele (1983) reported on the fleet operation of battery powered vehicles at the Southern Electricity Board. It was found that repair costs were 28 to 57% less and that the running costs were reduced by 60 to 65 % for their battery powered vehicles. The capital cost of comparably sized skid-steers is approximately $27,000. The projected capital cost for the battery powered skid-steer, based on the limited production of 50 vehicles per year, is approximately $30,000.

Skid-steering allows the vehicle to be turned quickly and to negotiate in confined spaces. The turning characteristics of a vehicle using skid-steering depend on the thrusts on the inner and outer wheel drives, on the

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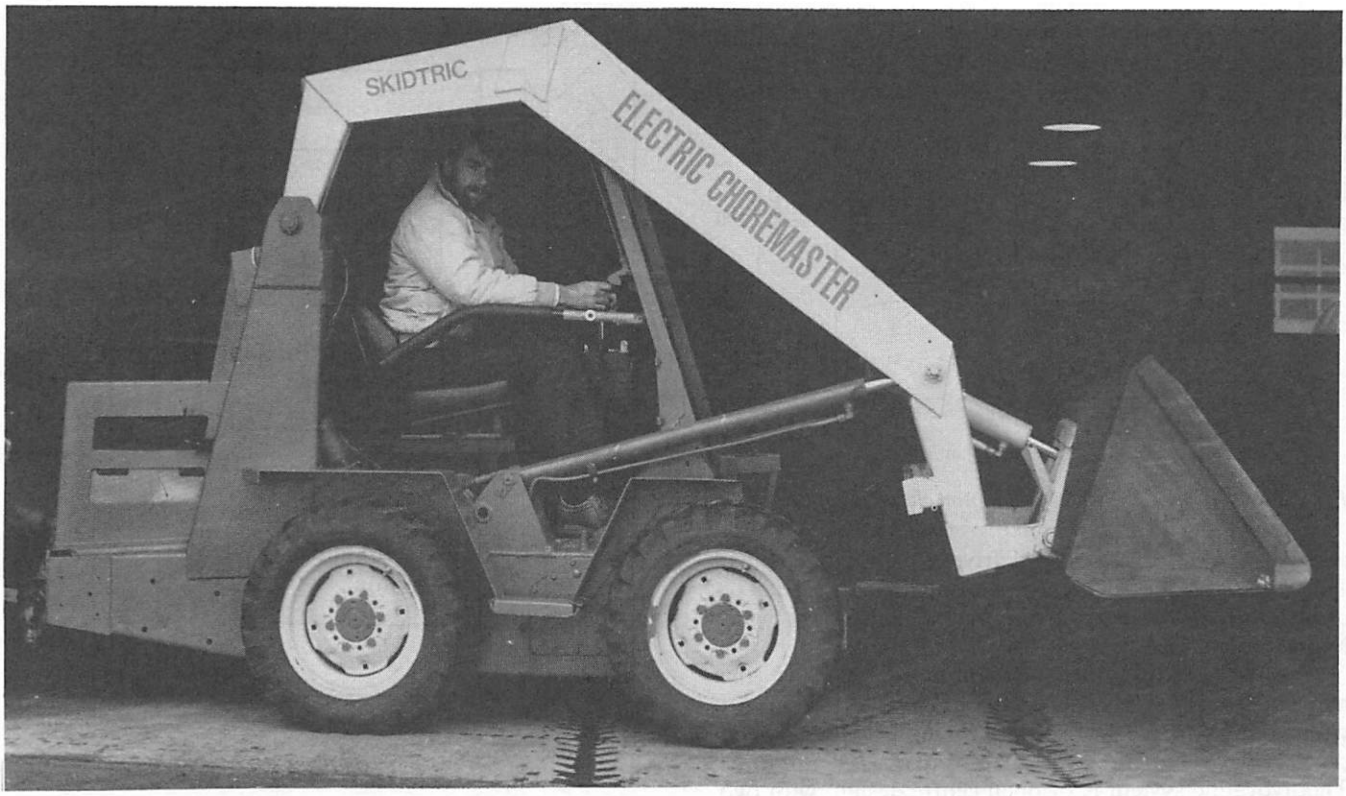

Fig 1 Battery powered skid-steertractor, driven by the author

resultant resisting forces opposing motion and on the moment due to the resistance to skidding exerted on the wheels by the ground. Turning in skid-steer mode can be made easier if, with a two axle vehicle such as the "Skidtric" (figure 1), the majority of the vehicle's weight is carried on one axle during the turn.

Design of the "Skidtric"

The "Skidtric" operating weight and its associated rated load were specified in accordance with the SAE Standard J732 (SAE, 1984). This standard requires that the appropriate rated load is determined as a function of the operating weight while enabling the stability of the vehicle to be maintained. The unloaded static weight distribution, including the bucket loader attachment, is

Table 1 Common features of skid-steer loaders

*Skid-steer model and make**	*Diesel engine power, kW*	*SAE rated load, kN*	*Operating weight, kN*	*Load to weight ratio*	*Wheel base, m*	*Overall height, m*
A1	31.33	7.34	20.08	0.365	1.07	1.85
A2	42.52	9.12	24.88	0.366	1.22	1.94
B1	33.57	7.56	26.53	0.285	0.98	2.11
C1		3.55	13.61	0.261	0.91	1.85
C2		4.45	16.10	0.276	0.91	1.93
C3		5.78	19.26	0.300	0.91	1.93
D1		5.12	17.88	0.286	0.91	1.93
D2		5.45	18.46	0.295	0.91	1.93
E1	32.08	6.67	26.68	0.250	0.91	1.93
E2	43.26	10.23	36.92	0.277	0.96	2.16
F1		5.34	20.12	0.267	0.94	2.03
F2		8.00	26.24	0.305	0.94	2.06
G1	20.88	4.89	19.74	0.240	0.89	1.97
G2		9.34	31.40	0.297	0.95	2.13

**Indicates a particular make and the number indicates the model*

approximately 74% on the rear axle and 26% on the front. These percentages reverse when the loader is carrying its maximum rated load of 7.52 kN with the bucket raised to its maximum forward reach. This value for rated load compares favourably with rated loads for commercially available skid-steers of similar size. Table 1 provides a listing of the common features of skid-steer loaders. The operating weight (ie the unladen vehicle weight) of the "Skidtric" results in a load to weight ratio of 0.279; the wheelbase is 1.42 m, the overall height 2.00 m and the width 1.50 m.

Specific design criteria for the "Skidtric" were developed by considering the vehicle weight, the maximum velocity and acceleration, the ground conditions, the slope, and the expected vehicle loads. Vehicle thrust values were calculated at breakaway, and at intermediate and maximum speeds of 7 and 19 km/h respectively. The "worst case" values assumed for breakaway (vehicle starting from rest) were as follows:

vehicle weight, 27 kN;
vehicle acceleration, 1 m/s^2;
coefficient of rolling resistance, 0.18;
drawbar load, 6.7 kN;
initial thrust, 19.6 kN;
thrust at the intermediate speed, 13.3 kN;
thrust at the maximum speed, 3.3 kN.

Based on these requirements, the appropriate torque-speed relationship for the series wound traction motors was determined. The actual characteristics of these dc motors is shown in fig 2.

The skid-steer loader has separate drive chains for each side of the vehicle. On the "Skidtric" these consist of chain cases which are welded to the vehicle subframe. Each chain case is driven by a 9.0 kW (one hour rating) series wound dc motor, coupled to the input shaft of a spur gear reduction of 4.76:1. A second reduction of 3.36:1 is accomplished by a chain drive connecting the

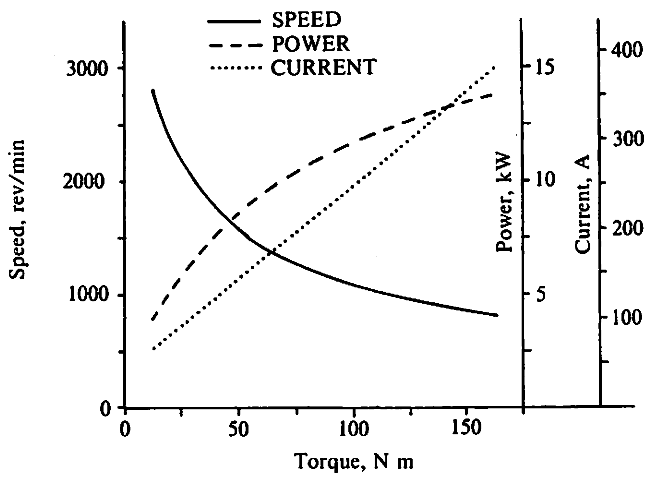

Fig 2 Direct current, series wound motor characteristics

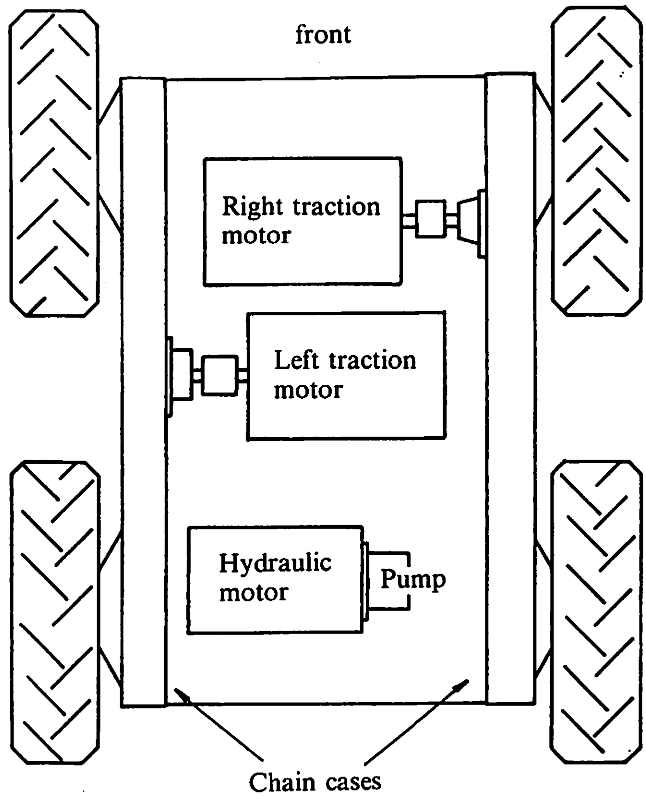

Fig 3 Drive train layout

two axles, providing an overall drive reduction of 15.99:1. This drive arrangement (fig 3) permits the "Skidtric" to operate in a similar manner to skid-steers with hydrostatic drive.

A third electric motor is employed to drive the hydraulic pump. This is a compound wound dc motor with a one hour rating of 9 kW. This motor drives a fixed displacement gear pump with an output of 2200 mm^3/rev. The hydraulic system is of open centre design, with two cable operated spool valves for control of the loader arms and bucket tilt. The maximum hydraulic load was dictated by the breakout force, as defined by SAE (SAE 1984). The maximum hydraulic power requirement was determined by considering a maximum lift time of six seconds for the rated bucket load of 7.5 kN. The necessary

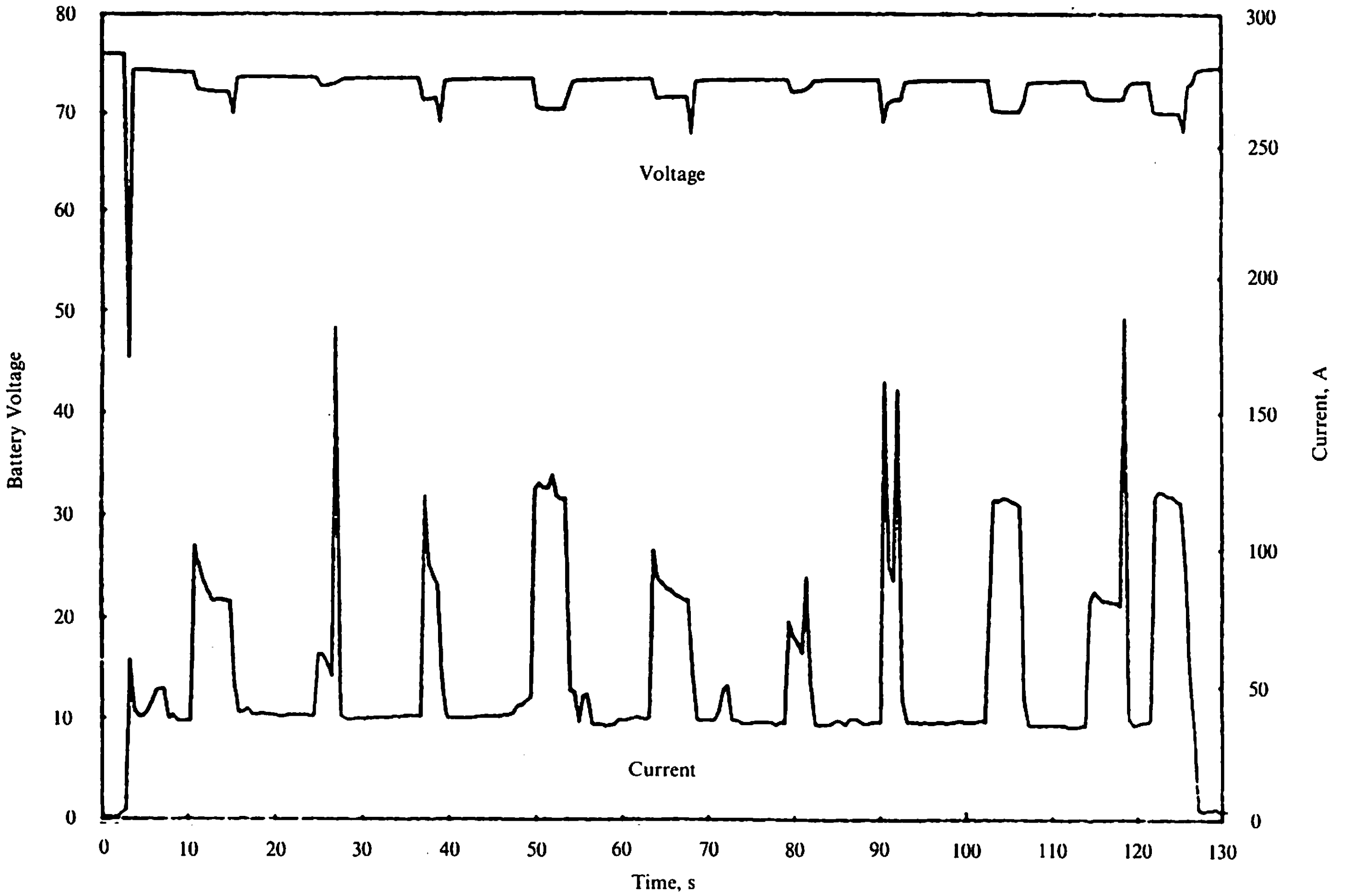

Fig 4 Voltage and current against time with loader being raised and lowered (hydraulic motor)

flow rate for this load was determined to be 40 l/min. The no-load lift time for this pump was determined to be 4.5 seconds. Lift and lower times for the loader arms and bucket, with no additional load, were found to be approximately 4.7 seconds. In fig 4, values of battery current and voltage were plotted with respect to time as the loader was raised and lowered. The current peaks correspond to the lifting and lowering of the loader bucket and the base value of approximately 40 A is associated with the continuous running of the hydraulics motor with the control valves in the neutral position. In view of the relatively large power requirement for operating the hydraulic pump continuously, this has been changed to a demand activated system whereby the pump is only driven when the operator moves the control lever for the spool valves.

Loader arms and operator's cab

Considerable attention was paid to the design of the operator's cab and to the layout of the controls. A full scale wooden model of the cab, the operator controls, and loader arms was used to evaluate several design options. Of primary concern was the method of entry to and egress from the cab. All other skid-steers have been designed with operator access at the front of the vehicle. This requires the operator to climb over the bucket making access difficult, if not dangerous. Side entry was adopted as a means of improving this design feature. The side entry stipulation meant that the loader arms had to be shaped to permit adequate access space while retaining the required lift specifications in terms of height and reach. Similar considerations dictated the positioning of the hydraulic lift cylinders.

Several safety features were incorporated to afford the operator reasonable protection. The operator's seat was fitted with a safety switch which prevents movement of either the loader or the vehicle without an operator in position. The seat also includes a lap belt. A safety restraint linkage lowers around the operator in the working position. This serves to prevent the operator from being thrown forwards or sideways during operation of the vehicle. Joystick control levers, for vehicle motion and for the hydraulic rams, are attached to this linkage. This mechanism pushes conveniently away from the operator for egress from the vehicle. However, the operator is obliged to use the safety restraint mechanism in order to operate the vehicle. Small side doors prevent operator contact with the lift cylinders throughout their entire range of movement. These triangular shaped doors swing aside allowing unobstructed access for the operator.

A computer program was used to size the loader arms and kingposts. This program simulated the movement of the loader arms through their full range, and computed the forces at intervals of 25 mm. Input variables included the lengths and angles of the structures, maximum work angle of the loader arms, initial cylinder angles, retracted and extended cylinder lengths, bucket weight, rated load and maximum horizontal thrust. The maximum forces for each position were retrieved and applied to a stress analysis and sizing routine where an overall factor of safety of 4.5 was used based on 3.0 for dynamic loading and 1.5 for static design. The output from the program yielded values for the cross sections of the loader arms and loader kingposts at every interval along their structural centre lines.

Battery and controllers

The batteries used for this vehicle are in four packs, each consisting of nine, two volt cells, housed in steel cases. This arrangement provided a nominal operating voltage of 72 with rated energy capacity of 320 A h, or 23 kW h. The battery capacity, at the six hour discharge rate, was measured in the laboratory at South Dakota State University after four complete charge and discharge cycles. Resistor banks were connected in parallel to provide a discharge load for the battery. An adjustable water rheostat was also used to control the current discharge rate within 0.1 A of the desired setting. Based on the rated battery capacity of 320 A h, the constant current discharge rate for the six hour test was 53.2 A. Battery voltage was monitored across the main terminals and also at nine, four cell, groups. Five thermocouples were used to monitor the temperature of four randomly selected cells, and ambient temperature. The discharge test was terminated when the average cell voltage reached 1.7.

The battery discharge test lasted a total of 5.4 h and resulted in 20 kW h of energy being discharged. This value was slightly lower than the rated value but this was expected at this stage in the life of the battery. It is normally anticipated that a deep discharge battery must complete at least twelve charge and discharge cycles before developing its full capacity.

The two traction motors are controlled by two silicon controlled rectifers, one for each motor. The silicon controlled rectifier is a semi-conductor device used as a latching switch. It can be turned on by the momentary application of a control current to the gate terminal of the silicon controlled rectifier. In the "Skidtric", the drive to each motor is interlinked through a proportioning control. The movement of the driver operated joystick is monitored and the controller supplies power to the two drive motors, proportionally. At a pre-set point, the in-board drive motor reverses. For a 90° turn, the motors turn at the same speed, but in opposite directions. The controller provides for stepless adjustment of motor speed, and for quick and easy vehicle steering.

Braking is also provided via the controller. This is accomplished by supplying a small retarding torque to the motors. The magnitude of this retarding torque can be controlled, within limits, by the operator. This technique is referred to as "plugging". Conventional, foot operated, hydraulic disc brakes are also provided.

Conclusions

Preliminary testing and evaluation suggests that the battery powered skid-steer loader designed and constructed at South Dakota State University has performance characteristics similar to those for commercially available skid-steer loaders of similar size. Skid-steer loaders are used in agriculture and the building industry on an intermittent basis. This represents a specialized application which is ideally suited to the characteristics of battery powered vehicles. There are two key factors which lend themselves to further investigation; the energy savings which result from using battery power in comparison with diesel fuelled skid-steer loaders, and the time for which the battery powered skid-steer loader can be used. In addition to laboratory testing designed to determine the operating characteristics of the "Skidtric", industry evaluations are to be obtained by having the vehicle operated by current users of skid-steer loaders.

Acknowledgements

Acknowledgements are extended to the National Rural Electric Co-operative Association and the Agricultural Experiment Station of South Dakota State University for funding this project, and to Sperry-New Holland for their donation of equipment. Also acknowledged are the considerable inputs to this project made by Kellen Chicoine, Les Christianson, Bruce Kocer, Don Froehlich and Greg Hanson of the Department of Agricultural Engineering, as well as Dennis Helder and Wayne Knabach of the Department of Electrical Engineering, at South Dakota State University.

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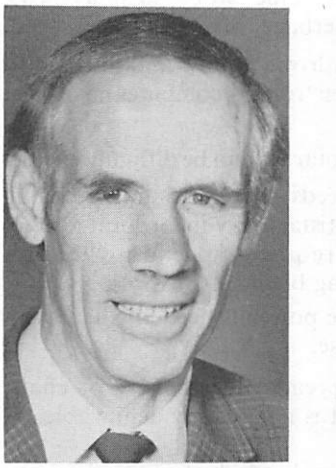
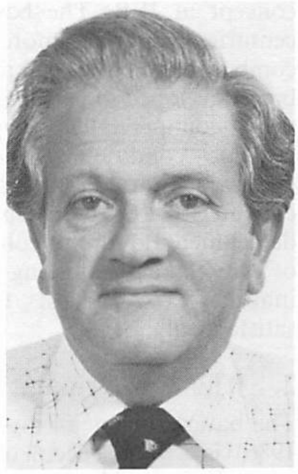
A new stripping header for combine harvesters

W E Klinner, M A Neale, R E Arnold





Above: M A Neale
Above right:
W E Klinner
Right:
R E Arnold

Summary

A SEED stripping system using flexible crop elements has been under development at the AFRC Institute of Engineering Research (IER) since the Autumn of 1984. The concept can be distinguished most clearly from the prior art by the design and construction of the crop engaging teeth, which ensure 360 degree stripping of plant stems and satisfactory performance in unfavourably presented and lodged crops. The potential of the system was assessed initially by adapting existing field and laboratory rigs, and this work led to the design, construction and evaluation in 1985 of a 3.6 m wide stripping header for a conventional combine harvester.

During the first season of use the effects of crop and operational variables were observed and measured, and comparisons were made with the performance of sthe combine when fitted with its normal cutting table. Provided adequate rotor speeds were used, seed detachment from the stems was always good, and with correct settings there was no tendency for the rotor to become wrapped or to uproot crop. Intake of material other than grain (MOG) varied from a few percentage points in standing crops early in the season to around 50% in very mature, tangled or lodged, late crops. Minimum front end losses attributable to the stripping rotor were approximately 50 and 80 kg/ha in barley and wheat respectively.

In consequence of the reduced straw intake, work rates and grain outputs were increased at given loss levels. On the two occasions when accurate measurements of relative straw walker and sieve losses were made, the maximum improvements due to the stripper header were 86% and 107% in barley and wheat respectively. Tighter concave settings were needed for stripped material.

Very long wheat lying away from the stripping rotor could not be harvested as effectively as by a cutting table with lifters fitted. However, regardless of the direction of harvesting, laid barley could be recovered more efficiently by stripping; in one instance 1.4 t/ha more, representing 23% of the available grain yield, was harvested.

1. Introduction

In response to user demand the capacity of commercial combine harvesters has been increased substantially in the past three decades by scaling up and fitting bigger engines, and by the introduction of rotary threshing and separating mechanisms. Today the largest machines are approaching the limits of physical size it is permitted to transport on the highway, of weight it is sensible to impose on the soil, of first cost users are prepared to pay, and of design and functional complexity which operators

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Wilf Klinner was Head of Field Machinery Division at the AFRC Institute of Engineering Research until his retirement in 1986. He is now an Innovations Consultant near Woburn Sands. Mike Neale is from the Machine Engineering Division of the AFRC Institute of Engineering Research and Roger Arnold, a Consultant Agricultural Engineer near Luton, who is also a retired member of the AFRC Institute of Engineering Research.

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and service personnel of average ability can cope with readily. Nevertheless, even higher outputs are being called for to reduce production costs and help to maintain farm profitability, increase the safe margin of harvesting capacity in difficult seasons, and improve timeliness and thus provide a bigger 'window' on the successor crop. Other limiting aspects of existing combine harvesters, methods of use and straw disposal include the following:

- Machine performance can be poor in difficult conditions and in some crops such as peas, beans, linseed, herbage and sugarbeet seed.
- Straw in large windrows is slow and difficult to dry, especially when 'rotary' combines have been used.
- Windrows from 'rotaries' can be difficult to bale.
- Combine straw needs chopping and spreading before it can be satisfactorily incorporated. Wet windrows can require spreading before satisfactory burning becomes possible.
- Much extra engine power is needed when straw choppers are in use.
- Weed seeds are spread and recovery of chaff, were it required, it is not readily achievable.

It was considerations of this kind which were taken into account in the development of the in situ seed stripping concept at IER. The basic idea of grain stripping is centuries old, and in more recent times static and rotary comb systems have been marketed. However, none have been developed to performance levels which would make them commercially acceptable under the crop and climatic conditions which are typical in Europe. Particular shortcomings have included high shatter losses caused by crop disturbance, incomplete grain detachment, failure to collect detached grains, blockages of essential crop aligning or stripping components, and inability to harvest tangled and lodged crops satisfactorily.

2. The new stripping concept

The basic principle of the new stripping system (Klinner 1986) is a high speed, overshot combing mechanism, which is covered by a curved hood with height-adjustable front section. Detached seeds and MOG are conveyed rearwards for collection or for feeding into a combine harvester or other mechanism capable of performing the functions of finishing thresher, separator and cleaner. Whilst the principal component may be a single horizontal rotor, it can also be a full width rearwardly inclined belt or a multiple rotor arrangement. The stripping elements consist of transverse arrays of long, slender and closely spaced teeth, with a recess at the base between each pair. This design gives 360 degree stripping of seed from the stems. When the elements are made of resilient material, as is preferred, protection is achieved against damage from contact with the ground or foreign objects whilst harvesting short or lodged crops.

In fig 1 are shown four variations of stripping element which were used in early trials with a tractor mounted 1.5 m wide field rig and a 300 mm wide laboratory rig. Results were sufficiently encouraging to justify the design and construction of a 3.6 m wide stripping header for a commercial combine harvester in the mid-capacity range. Figure 2 shows in cross-sectional diagrammatic view the

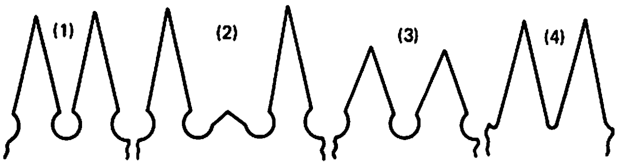


Fig 1 Alternative designs of stripping element: (1) slender arrow head, (2) spaced slender arrow head, (3) stubby arrow head, (4) simple serrated tooth

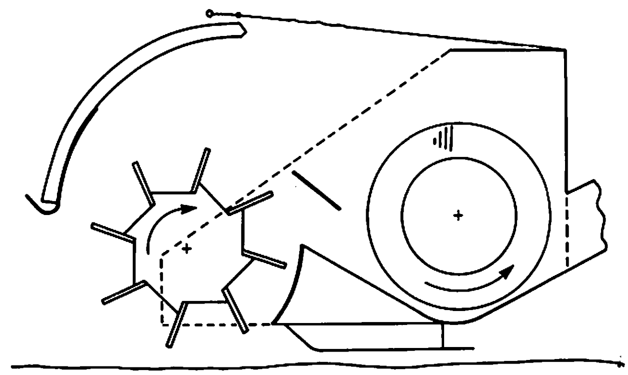
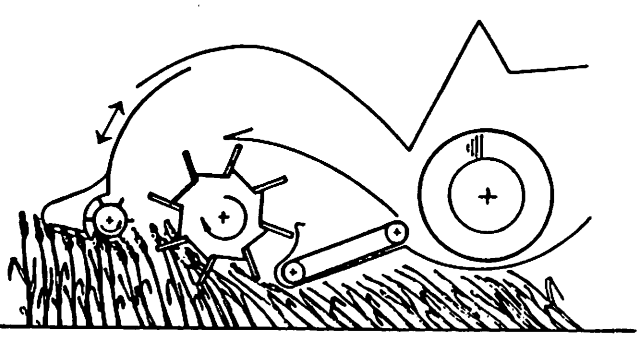


Fig 2 Cross-sectional diagrammatic view of basic stripping header for a combine harvester

basic form of stripper header evaluated in 1985. The material collected by the front rotor is conveyed to a conventional, centre-delivering crop auger which feeds it into the crop elevator of the harvester. Between the stripping rotor and auger are provided a full width ramp at the bottom and a flexible baffle above, both to prevent free grains from ricocheting forward and being lost. A flexible cover between the rotor hood and rear wall of the header also arrests flying grains and allows air to escape. The skid under the header is so dimensioned that ground contact by the stripping elements is impossible in normal working conditions.

The alternative design in fig 3 has an additional feed assisting rotor in the front section of the height adjustable rotor cover and employs a belt conveyor between the stripping rotor and crop auger. Provision is made to allow air to escape rearward without loss of grain. Only the basic form of stripping header was evaluated in year one, when the results given in the following sections were obtained (Klinner *et al* 1986).

Fig 3 Cross-sectional diagrammatic working view of alternative design of stripping header



3. Field performance of experimental stripping header

Harvesting trials and measurements were carried out on 44 occasions in 14 different crops of Spring and Winter cereals, combineable peas and linseed. A feature of the 1985 harvest season was that in most of the cereal crops, but particularly the wheat, grain heads were distributed over most of the crop height as a result of the stems bending and breaking at early stages of maturity.

3.1 Evaluation procedure

The combine, to which the conventional cutting table and the experimental stripping header could be fitted, was adapted for the determination of straw walker and sieve losses, using 50 m long calico sheets for efflux collection, following established procedure (Hebblethwaite and Hepherd 1961, Anon 1967). For determining header losses, shallow, plastic framed collecting trays lined with towel cloth were used which measured approximately 610 mm long x 150 mm wide x 25 mm high. The trays were placed between drill rows 8 to 15 m in front of the combine, one near each extreme of the cutting width and 3m in the centre section within the wheel track. The combine was then driven over the trays at the selected forward speed and stopped before any efflux from the rear could fall onto them. The drive was disengaged and the header raised, to enable the trays to be removed in safety. Each tray was emptied, and the grain collected was cleaned, weighed and recorded. Whenever the header height was insufficient to allow loss trays to be used, particularly in laid crops, counts were made of pre-harvest losses in front of the combine and of total losses after the header had passed. The counting frames used for this purpose had an enclosed area of approximately $0.1m^2$. In combineable peas seed losses were collected from an area of $2m^2$.

The power requirement of the stripping rotor unit was measured on the tractor mounted field rig in the conventional way, using a pto torque transducer.

3.2 Front end losses

During the early commissioning period performance improvements were achieved through component and design modifications and the optimisation of settings. The most effective adjustment was found to be the vertical clearance of the leading edge of the rotor hood relative to the bottom-dead-centre level of the stripping rotor. Header losses were at a minimum when this was approximately 300 to 370 mm, depending on crops and conditions. As an example, the effect on header losses of changing the vertical hood clearance relative to the stripping rotor is shown for Winter wheat, var Avalon, in fig 4. The horizontal hood-to-rotor clearance at the entrance to the crop flow passage was of secondary importance; at less than 90 mm there were detrimental effects in some crops and conditions.

The most effective design of stripping element was that shown at (1) in fig 1. Designs (2) and (3) recovered less stripped off grain, and design (4) did not achieve 360 degree stripping consistently. In cereals a rotor tip speed of 18 to 22 m/s gave the required efficiency of dislodging the grain from the heads and recovering it. Minimum header losses were 50 kg/ha in Spring barley and 80 kg/ha in Winter wheat. Laboratory studies of the stripping process subsequently indicated that around 50% of the

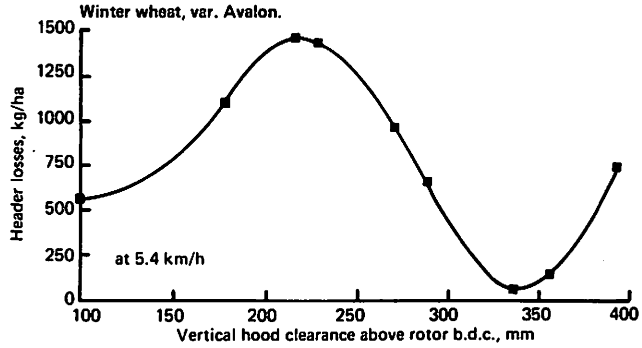


Fig 4 Effect of vertical hood clearance above rotor bottom-dead-centre on stripping header losses at constant forward speed

header losses may be avoidable by additional design improvements at the interface between the stripping rotor and the crop auger.

On several occasions stripping header losses decreased with increasing forward speed. Maximum practicable forward speeds were almost invariably higher with the stripping header. An example of this effect is shown in fig 5. Whilst the highest attainable combining speed was 4.5 km/h with the conventional cutting table, a speed of 7.5 km/h was possible with the stripping header at a slightly lower front end loss of whole or part heads.

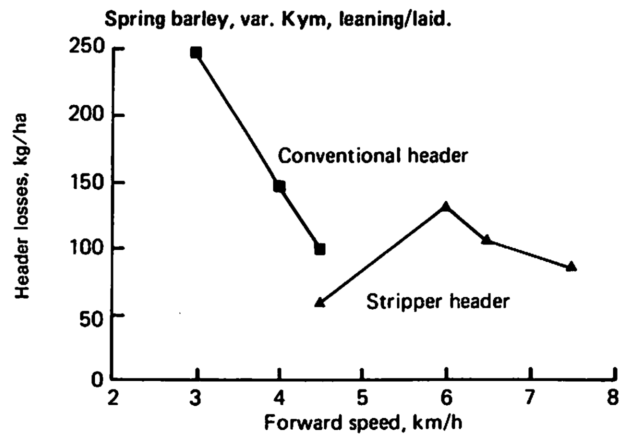


Fig 5 Effect of forward speed on the loss of whole and part heads incurred with alternative combine headers

On one occasion in severely laid barley harvested in Scotland late in the season a 1.4 t/ha higher grain yield was obtained by stripping the crop than by using a conventional machine with crop lifters fitted. The extra yield amounted to 23% of that available. Laid wheat could be harvested satisfactorily, provided it was lying towards the header or across the direction of travel. Losses of unrecovered heads were higher than with the conventional table when the crop was lying away from the combine.

Linseed was harvested successfully at a rate higher than had been possible with the farmer's own conventional combine and at lower losses. However, on two or three occasions the non-standard auger on the experimental header had to be cleared of straw, which had a tendency to cling to it and gradually build up from the centre section outwards.

A comparison of header performance in swathed and uncut peas for combining peas showed that the stripping header was capable of harvesting both marginally more effectively than the conventional cutting table. In mid-November a second crop of peas of a high protein variety was harvested with the stripper header after the farmer had withdrawn his combine and abandoned the field.

3.3 Straw intake

In barley and wheat crops which had only just reached combine ripeness the MOG detached by the stripping rotor contained practically no straw, consisting mainly of flag leaves and awns or chaff. With progressing maturity the quantity of straw detached increased until in some laid, brittle and damp late season conditions approximately 50% of the straw was removed by the stripper.

In addition to the crop characteristics, some operational parameters affected straw detachment. The most pronounced effect was due to variation of stripping rotor height, and the relationship measured in one crop of spring barley is shown in fig 6.

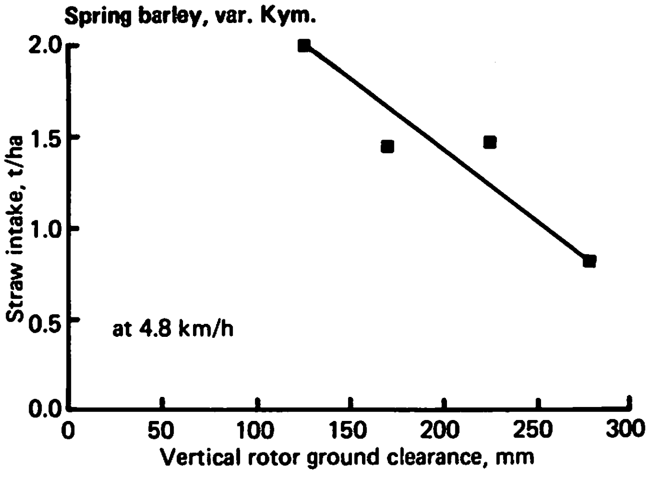


Fig 6 Effect of varying rotor ground clearance on straw intake at constant forward speed

3.4 Effects of type of header on straw walker and sieve losses

In one crop each of Spring barley and Winter wheat the full relationship between grain output and the straw walker and sieve losses was determined with both types of header. The sample size for each loss run was 50 m x the full working width. The combine was first adjusted, with the cutting table fitted, until satisfactorily threshing and separating performance was obtained at a forward speed appropriate to the prevailing conditions. Initially, identical combine settings were used irrespective of the type of header, but in both crops the fastest run with the experimental stripper fitted was repeated with the concave clearance reduced by one graduation.

The results for Spring barley are shown in fig 7. Substantially higher harvesting rates were possible with the stripper header; improvements in terms of grain output over the conventional cutting table at identical concave settings were approximately 50 to 60% at combined straw walker and sieve loss levels of 100 to 250 kg/ha. At the reduced concave clearance the combined losses were reduced by 49% to less than than 150 kg/ha at a grain output of 13.5 t/ha. This is an exceptionally good result for the size of combine harvester, indicating relatively flat curves up to that throughput level and confirming the advantages of minimising straw intake.

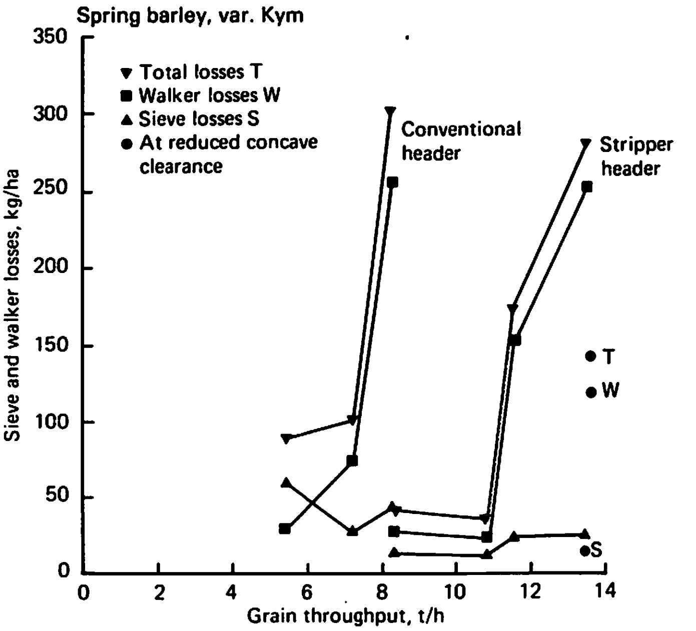


Fig 7 Effects of throughput on straw walker and sieve losses in spring barley, var Kym

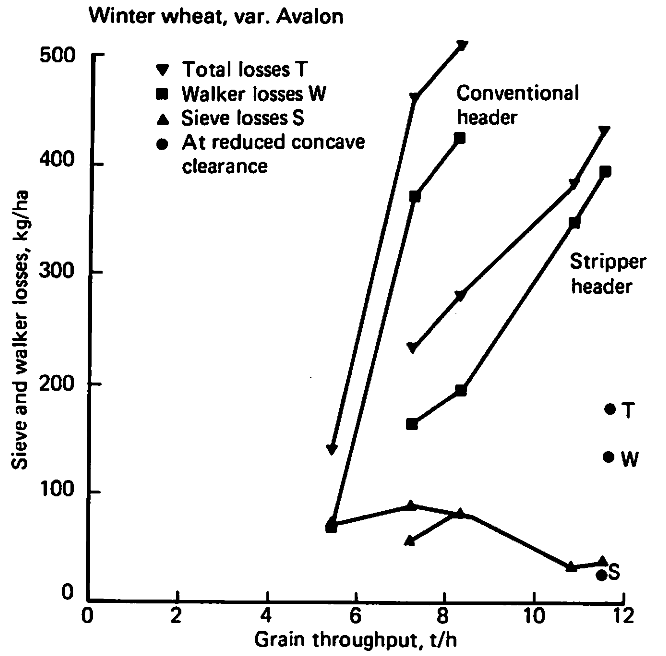


Fig 8 Effects of throughput on straw walker and sieve losses in winter wheat, var Avalon

The results of similar comparative loss measurements in Winter wheat are given in fig 8. Again, they show a substantial difference in favour of the stripper header. However, slower speed runs would have been needed to define grain output at straw walker plus sieve loss levels of less than 200 kg/ha. The repeat run at the fastest forward speed, but with the concave closed by one graduation, reduced the combined straw walker and sieve losses by 58% to 180kg/ha at a grain output of 11.6 t/ha. This represents an increase in output of 107% over the conventional header at identical loss levels.

Visual inspections, made on most occasions when comparative work was carried out, indicated that the stripping header caused no noticeable disadvantage in terms of the damaged grain and impurities contents of the harvested sample.

3.5 Power requirement

With the rotor unobstructed by crop the no-load power consumption was 0.7–0.8 kW/m. In work the power requirement per meter of rotor width varied between 2.0 kW and 2.9 kW in barley and wheat respectively at 4 km/h and between 2.8 and 3.9 kW at 6 km/h. Whilst rotor speed affected power requirement only marginally in wheat, it was significantly higher in barley at 635 rev/min than at 440 rev/min. The measurements were made in crops of normal condition and average straw length. Observations indicate that substantially more power is required for stripping lodged grain and herbage seed crops.

4. Prospects for in situ seed stripping

Provided that research and development progress is maintained and commercial introduction becomes justified, the seed stripping concept will almost certainly be marketed first in the form of retrofit headers for existing combine harvesters of all the important makes. Figure 9 shows the first commercial prototype stripping header designed and built for replacing the normal cutting table on a conventional combine harvester.

Fig 9 Commercial prototype stripper header built by Shelbourne Reynolds Engineering Ltd, Stanton, Nr Bury St Edmunds, Suffolk

If commercialisation proceeds satisfactorily, 'new concept' harvesters will probably be developed in which the free grain is separated immediately and the mechanisms for final threshing, separation and cleaning are matched to the performance characteristics and the material delivered by the stripping system. Such units could be self-propelled but may be designed for front mounting, preferably on reverse drive tractors.

A further alternative is a strip and collect system in which all the detached material is taken to the farm for processing into feed or for optional separation. Any unwanted MOG can be pelleted with or without additives for sale off the farm, where appropriate, or it may be burnt loose or in wafered form to generate heat for drying grain or other crops and for heating buildings. By dimensionally adapting the stripping rotor to suit specific crop habits and characteristics, the principle of in situ stripping should be adaptable also to the harvesting of dwarf crops like navy beans and wild white clover, to other legume seeds, to tall stiff stemmed rowcrops like maize and sorghum, to other oilseed crops like flax, to the defoliation of some forage, culinary and pharmaceutical crops, and to the collection of blossom and possibly other specific plant parts.

5. Disposal of the residue

For the stripping concept to become accepted quickly and by the largest possible numbers of farmers, machines and methods will need to be developed which make the disposal and utilisation of the residues of the stripping process quick and efficient. Ad hoc trials have shown already that stripped straw dries rapidly after rain, can be burnt easily and is fairly readily incorporated by slightly adapted ploughs and heavy disc implements. If harvesting of the straw is required, it needs to be windrowed first, but this may well be done ultimately by a centre-delivering swather mounted at the front of the tractor pulling the baler. Cutting down the straw immediately behind the stripping header and then merely windrowing it at baling is a further possibility.

Several years of observations and experimentation will be necessary to provide answers to questions relating particularly to the effects of long straw incorporation on the yields and pest and disease problems of successive crops.

If necessary, residual straw can be chopped, possibly by mechanisms designed specifically to utilise the vertical alignment of the crop stems. Choppers could be mounted on the front of tractors performing the first incorporation pass, thus saving a separate operation.

6. Conclusions

- The resistance of crops to uprooting is sufficient to permit removal of seeds by in situ stripping, provided the speeds and settings of the rotary con-mechanism are matched to crops and conditions.
- The new design of stripper harvester uses crop engaging elements which give advantages over previous designs, particularly 360 degree stripping of plant stems, ability to recover lodged crops, and damage resistance.
- Main advantage of stripping headers on combine harvesters is the reduction of straw intake which leads to higher harvesting rates.
- Stripping efficiency is affected by machine design and operational parameters and by crop variables, particularly maturity.
- Lowest losses and straw intake in cereals are usually achieved within a few days of the crops reaching combine ripeness.
- Of the white straw crops barley is most readily harvested by stripping and even in severely lodged conditions can be recovered more efficiently than by conventional cutting tables.
- A combine with stripping header may require different settings, particularly of the concave, than one with a conventional table.
- The power requirement for in situ stripping is several times that needed for cutting and feeding crop conventionally into a combine, but the power requirement for threshing and separation is likely to be less. Whether or not there is a net

gain in energy terms for the complete system, including straw disposal, requires further study.

- More development is needed to increase the efficiency of seed recovery by stripping in some crops and conditions and to extend the range of crops which can be successfully harvested by this approach.
- Research, to develop new machinery and methods, is desirable to overcome any problems associated with the safe, efficient and economical disposal of the residues of the stripping process.

Acknowledgements

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A cost model of straw conservation systems

J M Clegg and D H Noble

Summary

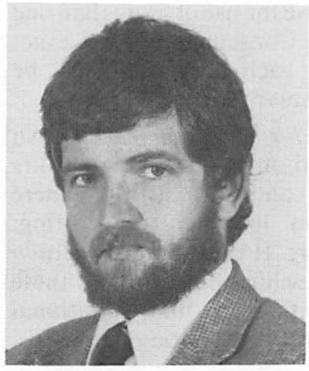
A MODEL has been produced which is capable of costing and comparing mechanised systems of straw conservation starting from straw in the swathe through to when it has been unloaded and stacked at some storage point. Results are presented and methods of cost reduction examined. These suggest that a cost of £10/t should be attainable by most farmers whilst contractors may be able to reduce this by up to £2/t. Fixed costs and repair and maintenance constitute the largest proportion of total costs (of the order of 40% and 27% respectively). Increasing bale density appears to be the most effective method of reducing costs — a doubling of bale density for all systems except the Hesston achieves a cost reduction of 25% to 30% (Hesston 16%). For the majority of systems minimum costs per tonne are achieved round about 1000 t baled, although for the Hesston with significantly greater capital investment the figure is more like 2000 t.

1. Introduction

In 1979 the Department of Energy commissioned Silsoe College (then the National College of Agricultural Engineering) to map the territorial distribution of all agricultural wastes and residues in the UK. In energy terms, approximately half the UK total of agricultural wastes was accounted for by cereal and oil seed rape straw (Larkin *et al* 1981). Consequently, in 1981, the College was further commissioned to investigate the acquisition and utilisation of straw for a fuel. The cost model described in this paper formed a part of that investigation.

The viability of straw as a fuel hinges on the cost of useful energy derived from its combustion, compared with that from competitor fuels, oil, gas and, principally coal. This cost is comprised of many factors and it was therefore necessary to determine the costs incurred at each stage of the route from straw in the swath right through to final combustion.

The model described in this paper has been used to calculate the cost of one of these stages, namely that of the on-farm collection of straw, ie baling, loading,



J M Clegg

D H Noble

transporting to the storage site, unloading and stacking.

The model has not been based on any particular farm but it is deemed to be generally applicable to all scales and types of operation. Machinery prices used throughout are the retail prices current at the time.

2. The baling systems evaluated

Using information from the farm survey carried out as part of the complete investigation (Clegg *et al* 1985), and with advice from ADAS, seven systems of straw baling and handling were selected for detailed analysis.

(i) Conventional baler and flat 8 accumulator,
(ii) Conventional baler and 56 bale transporter,
(iii) 1.5 m round bale and trailer,
(iv) 1.5 m round bale and balespike,
(v) 1.2 m round bale and trailer,
(vi) Hesston 4800 big bale,
(vii) Chopped straw.

3. Data requirements

Due to the way in which the data files are structured, the same computer program can be used to evaluate any system of straw conservation or indeed any mechanised crop harvesting system (Dowson 1985 and Crossley 1985). A detailed description of the program and the data used is contained in Noble and Clegg (1984).

The data used to evaluate each system of straw conservation has been split into four types:

3.1 General data applicable to any system

Crop areas and yields, bale carting distance from field to stacking site, labour rates, fuel costs, annual interest rates, scrap value of machinery and the annual cost of shelter, insurance and taxes.

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3.2 Machinery data

Initial purchase price, maximum life in hours and years, repair and maintenance costs and fuel use (if applicable).

3.3 Operations data:

(i) *Work rate:* For each operation a work rate is specified. The units vary according to the operation. Loading and unloading rates are in bales/man h. Baling is specified in t/h. Transport speeds are in km/h.

(ii) *Machinery usage.* Some pieces of equipment are used in more than one operation and similarly most operations involve the use of more than one piece of machinery. Consequently, the exact machinery usage for each operation must be defined for any particular system.

(iii) Annual time available for baling and carting. An upper limit is imposed on the number of hours available for baling and for carting, where carting is defined as loading, transporting, unloading and stacking. If the quantity of straw to be handled requires hours in excess of these limits then it is assumed that additional machinery capacity will have to be purchased.

3.4 Bale data

Bale weight, twine cost and the number of bales carried by each particular transport vehicle.

4. Calculation of fixed and variable costs

From the yield and cropping area data, the tonnage to be handled can be calculated, and hence using the operation rates, the total times required for each operation can be determined. From this the machinery usage in hours can be calculated and, using the limits imposed on annual time available for baling and carting, the number of machines required can be obtained.

Knowing this, the fixed costs of the equipment can be calculated. These consist of depreciation, interest on capital invested, and an amount to cover the cost of shelter, insurance and taxes. For equipment which is used on other enterprises in addition to straw conservation, an annual farm usage is assumed and the fixed cost of that item apportioned according to its usage in straw conservation, eg for tractors, an annual farm use of 1000 hours is assumed. If the calculated tractor usage for straw conservation is 400 hours, then the fixed cost of using that tractor for straw conservation is taken to be 0.4 of its annual fixed cost.

Six repair and maintenance classes have been created and each item of equipment has been allocated to a particular class. This classification roughly follows Culpin (1975) but modifications have been made by the authors as described later.

Annual fuel cost is worked out from tractor usage (hours) multiplied by fuel use (l/h) and by fuel cost (£/l). Labour cost is the product of labour rate (£/h) and the number of hours worked.

Finally, twine costs can be calculated from the number of bales handled, the amount of twine used per bale and the cost per metre of twine.

5. Results

For both baling and for baling and carting to store, six tables are generated by the computer program showing the total cost of each system and its constituent costs. A further table shows the total investment required for each system. Some of these results are reproduced in this paper.

The model was run over a wide range of input data, eg by transport distance (1.6 to 8.0 km round trip), by annual tonnage handled (100 to 4000), and by bale density. The results of one of these runs (variable annual tonnage) are displayed for four of the systems (fig 1).

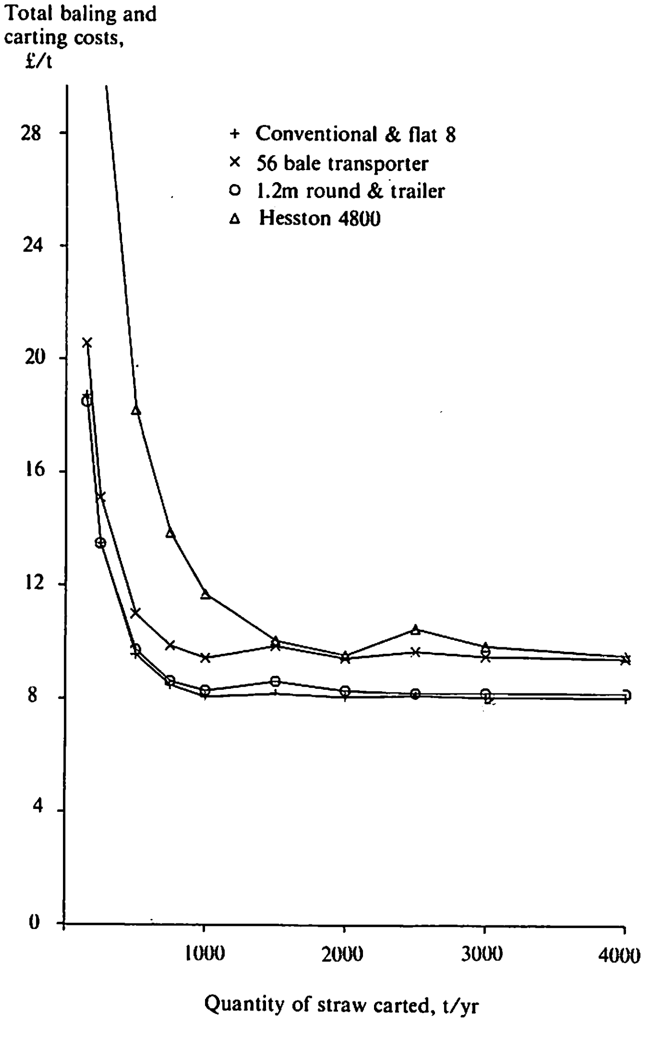

Fig 1 The relationship between total baling and carting costs per tonne and the quantity of straw baled per year assuming a mean transport distance of 1.6 km round trip

For all systems the cost per unit of output declines as output increases due to the fixed cost component being spread over a greater number of units. The reduction in unit cost becomes progressively smaller for each incremental increase in output as fixed cost becomes a less significant component of total cost. A small exception to this is that increases do occur in each of the curves at points where, due to the limits imposed on the available baling and carting hours, the model decides that additional machinery has to be purchased in order to complete the operations within the specified times. However these increases are minimal compared to the general trend of the curves.

Eventually a minimum cost is achieved. For the baling systems investigated this minimum cost occurred at about

THE AGRICULTURAL ENGINEER

Subject Index & Author Index

1986

The Agricultural Engineer

Subject Index 1986

Business management and marketing

Title of paper	*Author*	*Yr of publ*	*Vol no*	*Pt no*	*Page*
Environmental and governmental pressure on agriculture	Bowman J C	1986	41	3	77–83
Purchase prices of farm machines	Elbanna B and Witney B D	1986	41	4	106–112

Crop drying and storage

Title of paper	*Author*	*Yr of publ*	*Vol no*	*Pt no*	*Page*
Firing of boilers and furnaces with non-fossil fuels	Metcalfe J P	1986	41	1	17–27
Grain cleaning and grading: commercial needs and practices — present and future	Marshall J L	1986	41	1	34–35
Heat pumps for near ambient grain drying: a performance and economics feasibility study	Brook R C	1986	41	2	52–57
Putting theory into practice	Galloway A W	1986	41	2	62–67
Soft start for the reduction of starting currents for grain drying fans	Kneeshaw A R	1986	41	3	103–105

Cultivations and ploughing

Title of paper	*Author*	*Yr of publ*	*Vol no*	*Pt no*	*Page*
Tillage effects on growth, yield of maize and some soil properties — an experience at Dschang, Cameroon	Baryeh E A	1986	41	2	38–42
Development of a rotary soil shaper for raised beds	MacIntyre D	1986	41	4	139–140

Design, development and manufacturing

Title of paper	*Author*	*Yr of publ*	*Vol no*	*Pt no*	*Page*
A system to monitor tractor drive tyre radial deflection on-the-move	Hemingway P F and Grigor M	1986	41	1	11–16
Scottish Branch Inventions, Competition sponsored by the Bank of Scotland	Pascal J A	1986	41	1	32–33
The development and field trials of the A blade coulter for introducing seed into the soil	MacIntyre D, Gray A G and Sharp M J	1986	41	2	43–51
Electronics on farm machinery: more productivity or more problems?	Potter M R	1986	41	2	58–61
The introduction of new technologies	Matthews J	1986	41	3	70–76
Developments in combine harvester design	Garbers H	1986	41	4	113–119
Development of a rotary soil shaper for raised beds	MacIntyre D	1986	41	4	139–140

Drills, seeding and planting

Title of paper	*Author*	*Yr of publ*	*Vol no*	*Pt no*	*Page*
The development and field trials of the A blade coulter for introducing seed into the soil	MacIntyre D, Gray A G and Sharp M J	1986	41	2	43–51

Education and careers

Title of paper	*Author*	*Yr of publ*	*Vol no*	*Pt no*	*Page*
The Agricultural Engineer after the Finniston Report	Finniston M	1986	41	1	3–10

Title of paper	*Author*	*Yr of publ*	*Vol no*	*Pt no*	*Page*
Transport and handling					
Firing of boilers and furnaces with non-fossil fuels	Metcalfe J P	1986	41	1	17–27
Grain cleaning and grading: commercial needs and practices — present and future	Marshall J L	1986	41	1	34–35
Some experiences with the NAC-V eyemark recorder during agricultural selection tasks	Zegers D H A	1986	41	3	99–102
Straw compaction research	Neale M	1986	41	4	126–130
Straw densification for transport and use: baling and handling straw	Bull D A	1986	41	4	131–136
Institution matters					
The Agricultural Engineer after the Finniston Report	Finniston M	1986	41	1	3–10
Scottish Branch Inventions Competition sponsored by the Bank of Scotland	Pascal J A	1986	41	1	32–33
The introduction of new technologies	Matthews J	1986	41	3	70–76

The Agricultural Engineer

Author Index 1986

Author	Title of paper	Yr of publ	Vol no	Pt no	Page
A					
Arthey D	Quality of agricultural products	1986	41	3	91–96
B					
Baryeh E A	Tillage effects on growth, yield of maize and some soil properties — an experience at Dschang, Cameroon	1986	41	2	38–42
Bishop C F H	*See* Maunder W F	1986	41	4	137–138
Bowman J C	Environmental and governmental pressure on agriculture	1986	41	3	77–83
Brook R C	Heat pumps for near ambient grain drying: a performance and economics feasibility study	1986	41	2	52–57
Bull D A	Straw densification for transport and use: baling and handling straw	1986	41	4	131–136
C					
Carney P G and Dodd V A	Comparison of ventilation rates determined by four methods in commercial pig houses	1986	41	1	28–30
D					
Dodd V A	*See* Carney P G	1986	41	1	28–30
E					
Elbanna B and Witney B D	Purchase prices of farm machines	1986	41	4	106–112
F					
Finniston M	The Agricultural Engineer after the Finniston Report	1986	41	1	3–10
G					
Galloway A W	Putting theory into practice	1986	41	2	62–67
Garbers H	Developments in combine harvester design	1986	41	4	113–119
Gilbertson H G and Knight A C	Straw chopping	1986	41	4	120–125
Gould T	Wise investments for potato growers	1986	41	1	31
Grigor M	*See* Hemingway P F	1986	41	1	11–16
Gray A G	*See* MacIntyre D	1986	41	2	43–51
H					
Hemingway P F and Grigor M	A system to monitor tractor drive tyre radial deflection on-the-move.	1986	41	1	11–16

1000 tonnes of straw conserved per year (except for the Hesston with its much greater investment where minimum cost occurred at around 2000 t/yr). Once the minimum cost has been achieved, even increasing annual utilisation to extremely high levels has a negligible effect on total cost per tonne.

To achieve these minimum costs an area equivalent to 300–350 ha of wheat straw (600–700 ha for the Hesston) must be conserved annually, a figure only possible for a contractor or the largest farmers.

ADAS (1975) found in their survey that over 80% of farmers baled less than 200 ha of straw a year. Thus on purely financial grounds it would appear that the majority of farmers may be better off employing a contractor or participating in some form of co-operative venture.

6. Methods of reducing costs

The largest proportion of the minimum total cost is the fixed cost component which accounts for 40–45% of the total (table 1). The repairs and maintenance component is the next most significant at around 28%, followed by labour at around 18%. In practice, the majority of farmers are operating some way above the minimum cost (1000 t/yr) and thus the fixed cost component will have a greater significance. At 500 t baled per year fixed costs account for over half the total cost.

Table 1 Component costs as a percentage of minimum total cost for seven systems, (assuming a 1.6 km round trip distance)

System	Fixed cost	Repair and maintenance	Fuel	Twine	Labour
Conventional & flat 8	40.4	25.4	6.3	11.4	17.1
56 bale transporter	40.4	25.4	6.7	9.7	17.9
1.5 m round & trailer	43.6	27.3	7.1	3.1	18.8
1.5 m round & spike	41.3	27.2	7.9	2.5	21.1
1.2 m round & trailer	43.4	25.8	7.5	3.4	19.8
Hesston 4800	42.4	33.8	5.1	10.0	8.6
Chopped straw	47.2	24.8	7.6	0	20.3

6.1 Labour cost

Labour is a variable cost and indirectly related to system performance. The total labour cost is split roughly one third to two thirds between baling and carting (table 2). Thus attempts to reduce the labour costs per tonne would be better directed at improving bale handling. However, the scope is very limited and even dramatic increases in bale handling efficiency would produce only small decreases in total cost.

Table 2 Labour cost, £/t, for baling and transport to store, (assuming a 1.6 km round trip distance)

System	Baling only	Carting only	Total labour cost
Conventional & flat 8	0.50	0.83	1.33
56 bale transporter	0.50	1.16	1.66
1.5 m round & trailer	0.38	0.91	1.29
1.5 m round & spike	0.38	1.36	1.74
1.2 m round & trailer	0.45	1.17	1.62
Hesston 4800	0.24	0.58	0.82
Chopped straw	1.13	1.94	2.07

6.2 Repairs and maintenance

Estimating repair and maintenance costs is the most contentious area of any costing exercise. It is generally agreed that during ownership of any piece of equipment significant costs are likely to be incurred for repair at some time. However, the frequency and magnitude of these costs is open to some debate. In this model Culpin (1975) estimates have been used based on a proportion of initial purchase price. However, from discussion with straw contractors it appears that at a high level of use baler repair costs tend to be higher than those predicted by Culpin. Indeed, many contractors adopted a policy of renewing balers every other year so as to avoid costly repairs and even more expense due to down time. Consequently, an increasing rate of repair cost above 100 h/yr has been used, rather than Culpin's decreasing one. This has the effect of penalising those systems with expensive baling equipment, in particular the Hesston. The assumptions used are based on limited observations in the absence of more substantial data.

Repairs and maintenance accounts for about 25% of total cost (table 1). As no account has been taken of the cost of down time or of increased depreciation through frequent machine renewal, this figure can be thought of as an under rather than an over estimate. Clearly there is some room for improvement in baler reliability although the figures in table 3 would indicate that potential savings are limited. However, down time can be very significant for the operation of some contractors and larger farms, particularly when baling time is limited in difficult seasons. Consequently, machine reliability can assume a higher priority in the decision making process than is suggested by the contribution in table 3 of repairs and maintenance to total costs.

Table 3 Repair and maintenance cost £/t, for baling and transport to store (assuming a 1.6 km round trip distance)

System	Baling only	Carting only	Total R & M cost
Conventional & flat 8	1.21	0.80	2.01
56 bale transporter	1.19	1.17	2.36
1.5 m round & trailer	1.14	0.74	1.88
1.5 m round & spike	1.20	1.04	2.24
1.2 m round & trailer	1.17	0.94	2.11
Hesston 4800	2.67	0.53	3.20
Chopped straw	1.81	0.72	2.53

6.3 Fixed costs

Fixed costs are comprised of the following: depreciation, interest on capital, and shelter, insurance and taxes. All these three are related to the initial purchase price of the machine.

At maximum system utilisation, fixed costs account for over 40% of the total costs. The only ways to decrease fixed costs are to reduce the capital cost of the equipment, to extend the write-off period or to reduce interest rates.

Table 4 shows that a 50% increase in capital cost causes a 21%–24% increase in total cost when equipment utilisation is near maximum. The effect would be more pronounced at lower utilisation, eg at 500 t/yr, the average increase in cost would be 30%.

The write-off periods assumed for equipment in this study are generally in the region of 8 to 10 years which if anything err on the high side. Therefore, it would be unrealistic to assume that any savings could be made here.

Table 4 The effect of a 50% increase in capital cost on fixed and total cost, £/t, (assuming near maximum equipment utilisation and a 1.6 km round trip)

System	Utilisation, t/yr	Standard cost		Capital cost + 50%		
		Fixed cost	Total cost	Fixed cost	Total cost	Increase in TC, (%)
Conventional & flat 8	1000	3.41	8.07	5.11	9.77	21.1
56 bale transporter	1000	3.95	9.43	5.92	11.40	20.9
1.5 m round & trailer	1500	3.12	7.07	4.69	8.64	22.2
1.5 m round & spike	1500	3.45	8.27	5.17	9.99	20.8
1.2 m round & trailer	1000	3.74	8.29	5.61	10.16	22.6
Hesston 4800	2000	4.35	9.54	6.52	11.71	22.7
Chopped straw	1000	4.81	10.20	7.22	12.61	23.6

Table 5 The effect of a 50% increase in annual interest on fixed and total cost, £/t, (assuming near maximum equipment utilisation and a 1.6 km round trip)

System	Utilisation, t/yr	Standard cost		Increased rate + 50%		
		Fixed cost	Total cost	Fixed cost	Total cost	Increase in TC, (%)
Conventional & flat 8	1000	3.41	8.07	4.14	8.81	9.2
56 bale transporter	1000	3.95	9.43	4.79	10.27	8.9
1.5 m round & trailer	1500	3.12	7.07	3.81	7.76	9.8
1.5m round & spike	1500	3.45	8.27	4.18	9.01	8.9
1.2 m round & trailer	1000	3.74	8.29	4.54	9.10	9.8
Hesston 4800	2000	4.35	9.54	5.28	10.47	9.7
Chopped straw	1000	4.81	10.20	5.87	11.26	10.4

A 50% change in annual interest rate causes a 9%–10% change in total cost (table 5).

6.4 Bale density

Increasing the bale density reduces costs per tonne in several ways.

(i) *Carting:* as no manual handling has been assumed, loading and unloading performance is improved in terms of tonnes per hour as the same number of heavier bales are being handled. Similarly transport performance is improved as the weight of each trailer load is increased and therefore fewer journeys are required with a resultant decrease in total annual transporting time. Variable costs, fuel and labour are reduced per tonne as they are charged on an hourly basis. Also, increased performance results in less equipment use per year for a given quantity of straw. Therefore repair and maintenance costs are less and equipment life will be extended because depreciation is also reduced.

(ii) *Baling:* baling rate (t/h) has been assumed to be constant irrespective of bale weight. Therefore, the time required for the baling operation remains unchanged, and hence all the machinery and labour costs associated with this operation remain unchanged. However, twine costs are reduced because there are fewer bales to the tonne.

Clearly those systems, where carting comprises the larger proportion of total cost, will benefit most from increased bale densities (Table 6).

As carting distance increases, the effect of greater bale density on carting cost will become more pronounced. Additionally, but not considered in this paper, increasing bale density will also reduce the cost of subsequent storage and road transport and will result in a marked effect on the overall price of straw as a fuel.

6.5 The effect of carting distance on total costs

Table 7 and fig 2 show the increase in total baling and carting cost for greater carting distances. The rate of increase in costs is constant for each system apart from when extra equipment is required to complete the carting operation within the maximum allowable time. As is to be expected the systems carrying the greatest quantity of straw per trip are least affected by changes in carting distance.

By extrapolating the graph of carting cost (which comprises handling and transport cost) against carting

Table 6 The effect of increasing bale density on total cost, £/h, (assuming near maximum utilisation and 1.6 km carting distance)

System	Utilisation, t/yr	Total cost				
		Standard	Increase in bale density, 10%	25%	50%	100%
Conventional & flat 8	1000	8.07	7.70 (4.6)	7.26 (10.0)	6.72 (16.7)	6.06 (24.9)
56 bale transporter	1000	9.43	8.93 (5.3)	8.35 (11.5)	7.65 (18.9)	6.78 (28.1)
1.5 m round & trailer	1500	7.07	6.50 (8.1)	6.11 (13.6)	5.64 (20.2)	5.06 (28.4)
1.5 m round & spike	1500	8.27	7.87 (5.6)	7.26 (12.2)	6.60 (20.2)	5.67 (31.4)
1.2 m round & trailer	1000	8.29	7.87 (5.1)	7.38 (11.0)	6.79 (18.1)	6.60 (26.9)
Hesston 4800	2000	9.54	9.25 (3.0)	8.92 (6.5)	8.51 (10.8)	8.00 (16.1)
Chopped straw	1000	10.20	9.95 (2.5)	9.64 (5.5)	9.27 (9.1)	8.81 (13.6)

Note: Figures in brackets are the reductions in cost achieved, expressed as a percentage of total cost.

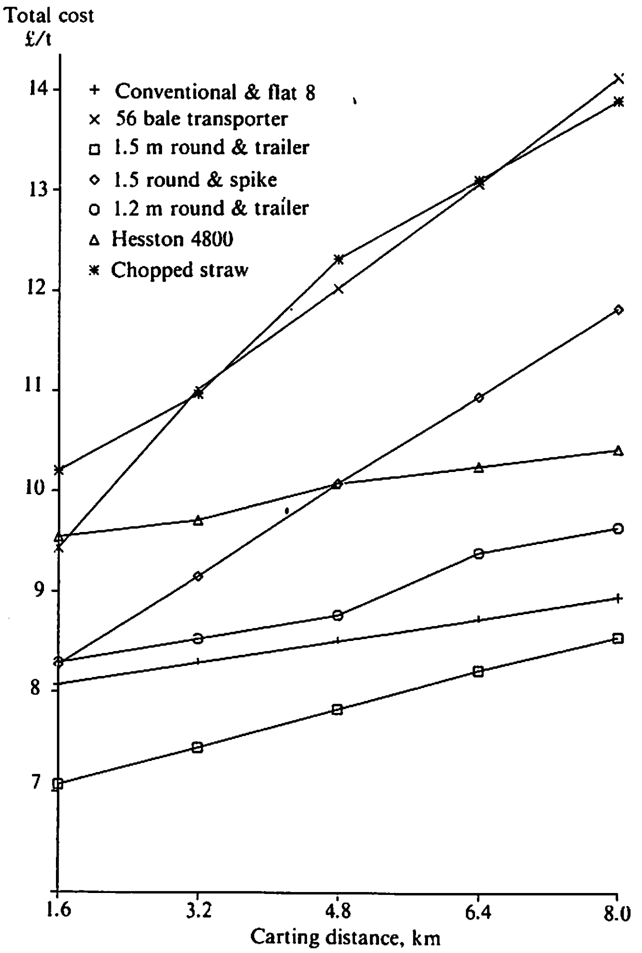

Fig 2 Total cost of baling and carting against carting distance for seven systems at near maximum utilisation

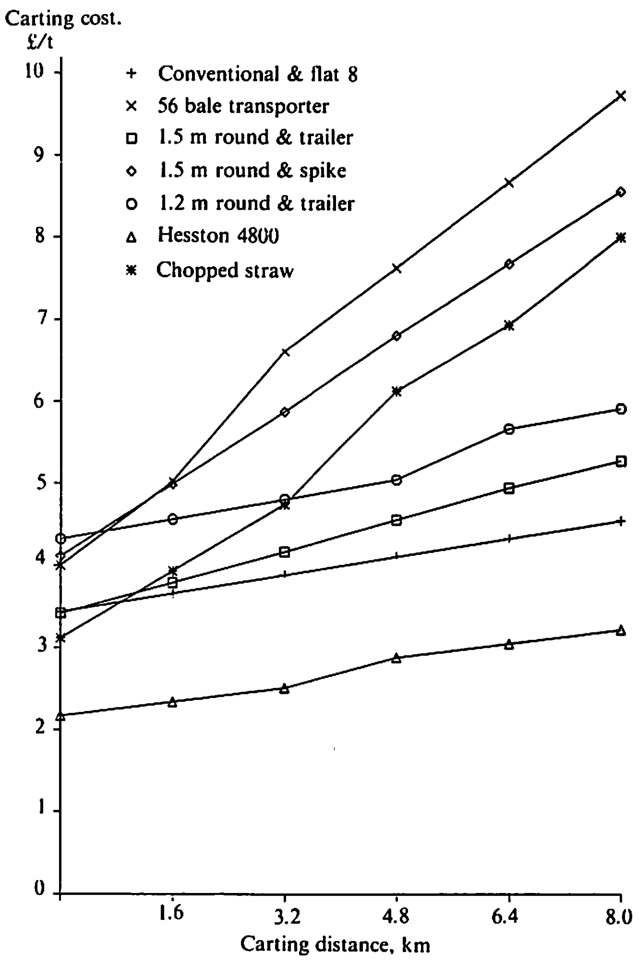

Fig 3 Carting cost against carting distance for seven systems at near maximum utilisation

distance, the intercept at zero kilometres gives the cost of loading, unloading and stacking (fig 3). It can then be seen that, whereas for short carting distances rapid loading and unloading is paramount, for longer distances the most important consideration becomes the quantity of straw carried per unit load. The handling and transporting advantages accruing from large, dense bales are clearly demonstrated by the Hesston system.

7. Conclusions

High levels of annual utilisation are required in order to achieve minimum baling and handling costs. For the majority of the systems the required level is around about 1000 t/yr. For the Hesston system, with significantly greater capital investment, the level is 2000 t. Below 750 t/yr total costs per tonne rise sharply.

Consequently it would appear that most farmers would benefit financially from the use of contractors or by sharing equipment for baling. The fact that neither of these options are extensively used reflects, amongst other factors, farmers' attitude to risk and their desire to carry out operations as soon as they are considered necessary.

Overall baling and carting costs vary considerably with the quantity of straw baled annually. However, a figure of £10/t would seem to be attainable by the majority of farmers whilst contractors may be able to reduce this by up to £2/t.

Table 7 The effect of increasing carting distance on total cost, £/t, and the increase as a percentage of total cost for 1.6 km round trip

System	Utilisation, t/yr	Round trip distance, km 1.6	3.2		4.8		6.4		8.0	
		£/t	£/t	%	£/t	%	£/t	%	£/t	%
Conventional & flat 8	1000	8.07	8.29	2.7	8.51	5.5	8.73	8.2	8.95	10.9
56 bale transporter	1000	9.43	11.02	17.6	12.03	28.7	13.07	28.6	14.13	49.8
1.5 m round & trailer	1500	7.07	7.44	5.2	7.83	10.7	8.22	16.3	8.55	20.9
1.5 m round & spike	1500	8.27	9.15	10.6	10.08	21.9	10.95	32.4	11.83	43.0
1.2 m round & trailer	1000	8.29	8.53	2.9	8.77	5.8	9.39	13.3	9.64	16.3
Hesston 4800	2000	9.54	9.71	1.8	10.08	5.7	10.25	7.4	10.42	9.2
Chopped straw	1000	10.20	10.97	7.5	12.32	20.8	13.11	28.5	13.90	36.3

The components of total cost, in order of magnitude, are fixed costs, repairs and maintenance, labour, twine and fuel. There appears to be little scope for reducing total costs by lowering twine or fuel costs and, although repair and maintenance costs are high, it should be noted that such calculations are only best approximations.

With the exception of the Hesston, a doubling of bale density brings about a 25% to 30% reduction (£2 – £2.50/t) in baling and carting costs over a 1.6 km round trip. For the Hesston, a reduction of 16% or £1.50/t is achieved. A reduction in the baling cost is brought about by a saving in twine but the major saving is in carting costs which represent 50–60% (Hesston 28%) of the total. Trailer loading rates are increased and fewer trips are required. Savings would increase with greater carting distances.

In the wider concept, the effect of bale density on subsequent storage and transport has a pronounced influence of the viability of the off-farm utilisation of straw.

Acknowledgement

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The combine business

J A Williamson

Summary

THERE will be a continuing reduction in the market size of total units sold and continuing movement towards larger combines. Manufacturers must be able to offer a competitive "price-performance package". There will be a need for built-in durability and long life of the combines as we can expect units to be used for longer periods in the future. Manufacturers will need to produce an excellent in-field service back-up for combine harvesters, including the training of operators.

1. Introduction

The combine is a very old piece of equipment. The first patent travelling thresher was invented in America by Lane in 1828, followed by two further designs by Ashbourne and Peck in 1835 and Carpenter in 1836. A fire in the American Patent Office destroyed most of the early records and the first combine that is really known is Hiram Moore's machine invented in Michigan in 1836 which looks very similar to a rotary combine — it was pulled by 20 mules. The first self-propelled combine harvester was invented by Berry in 1886 in Sacramento, it had a 3 metre header which was later converted to 12 metre and was known to combine 40 hectares a day. There was also the facility to remove the traction unit and use it to pull a 20 furrow plough once harvest had finished.

The first hillside combine was made in 1891 in Stockton, California. The first combines came to the United Kingdom in 1928 when a McCormick Dearing combine was brought into Hertfordshire by a farmer and a Massey Harris combine was brought in by the Institute of Agricultural Engineering at Oxford (the predecessor of the AFRC Institute of Engineering). The press reports of 1929 stated that English farmers said combine harvesters were not suited to this climate, although harvest costs were halved by their use. The first self-propelled harvester made in Europe was the Claeys machine introduced in 1952 at the Paris Agricultural Salon which was followed in 1953 by Claas with the Hercules machine.

Alec Williamson is Marketing Product Manager with Ford New Holland Ltd, of Basildon.

2. The combine harvester market

The current problems facing the agricultural industry have been well documented, one reference (Fox 1985) however, encompassed these problems particularly well, viz "Mechanisation reached its peak in 1979–80 and the decline began. A natural and normal consequence of a market approaching saturation. Not only are our customers upon whom the machine industry rely, well equipped and able, they can now operate with only a low level of new capital expenditure. Coupled to this; with a period of falling inflation and high real interest charges, providing the strongest motivation to leave cash in the bank or hold down borrowings; the stage is set for severe cutback. Against this background it is perhaps surprising that the decline has not been more severe. A partial answer is that farm machinery manufacturers have concentrated upon innovation as a means of increasing volumes and holding margins. However, such is the efficiency and performance of the new sophisticated products, that fewer of them are actually required so the total marketing units are bound to decline further".

There are a number of factors affecting the combine market — over production of food generally in the Western world, political influences, general confidences in the production of food and much larger and more efficient machinery.

The American market has probably had the biggest slump, reducing from a figure in 1976 of approximately 32,500 units to between 8500 and 9000 units in 1986. Europe, within the EEC, has been a little more stable, the figure having moved down from approximately 27,000 to about 16,500 over the same ten year period.

Within the EEC farm returns dropped by about 5% in 1986. It has been suggested that, because of the quality implications, the UK farmer could possibly lose as much as 6½% but this may not occur due to the drought in France. However, with reduced inputs on fuel costs, and on fertiliser costs, the income reduction is not sufficient to affect overall production methods which will result in 20 million tonnes of surplus grain predicted within the EEC by 1990.

The UK market has dropped dramatically this year, but this is not particularly unusual. The UK shows a predictable pattern with two or three years at a fairly steady level of sales and then drops suddenly after which it returns slowly to the former level. The market is down to just under 2000 units for 1986.

3. Combine harvester development (with particular reference to New Holland)

There has been an increasing trend towards machines with more power ever since the first self-propelled units were developed. The very first New Holland MZ combine in 1952 had 50 hp per metre of drum width, whereas the present TF 44 and 46 machines have 170 hp per metre drum width. The increase in power requirement is due to combine size increase, the need to drive straw choppers and harvesting difficult "fringe" crops.

The UK market has shown a dramatic increase in the size of combines. The number of 'walker' combines with drum widths greater than 1.5 metre and the rotary combine are now beginning to take a larger slice of the market, a steady progression to bigger and more efficient combine harvesters. However, whereas a farmer two or three years ago may well have made a decision to buy a combine larger than necessary to save on grain drying costs, that decision could be changed with the reduction in the price of oil.

On the product side, the expectations from purchasers of combine harvesters remain incredibly high. They expect very high capacity, low grain loss, (not greater than 1%), to work in any crop from rape to beans plus all the cereals. The customer is still asking the manufacturer to produce a modular combine harvester so that the engine, transmission and chassis can be used to mount a sprayer or a cultivator. And yet, that very same customer is content to buy a sugar-beet harvester, a potato harvester, a carrot harvester and an onion harvester for specific operations.

Innovation was mentioned in the earlier quotation as a means by which the agricultural engineering industry has maintained its market share. This will continue provided innovation

New Holland TF44 combine harvester

results in a benefit to the customer. In the operation of threshing, for instance, New Holland have made a number of changes to improve grain stripping and separating. In grain cleaning, there have been improvements in self-levelling, on fan performance and on the types of sieve.

4. Training

New Holland trained about 900 operators last year, they came on courses to learn about their combines, Moreover, just under a 1000 man days were spent at Aylesbury by dealers' personnel learning how to maintain and service combine harvesters.

The Laverda transverse rotary combine concept

by P Bosworth

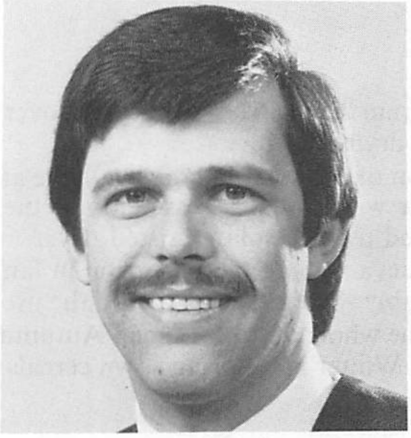
LAVERDA, a wholly owned subsidiary of Fiatagri, was founded in 1873 and has been producing harvesting machinery for over 100 years. New combines benefit from over 30 years' experience of harvester design and manufacture.

This engineering design experience and practical expertise has resulted in the marketing of successful straw walker combines, specialist hillside self-levelling combines and culminated in an innovative non-conventional combine, the MX 240 transverse rotary designed for European conditions.

Some of the requirements taken into account, when the MX concept was first designed were: high capacity, compatability with all types of crops, high cleaning efficiency, good manoeuvrability as road regulations become stricter, accessibility for service, operator environment, ease of control and good straw recovery by baling.

There are three functional groups: the header (5.5 or 6 metre width of cut) including the thresher-separator, the base unit housing the cleaning system with the grain tank, and the power transmission unit.

The header has a full width skid and the knife is operated at 550 cycles/min. by a reliable wobble drive in an oil bath for fast and clean cutting. A large diameter reel and full width auger with retracting tines gather the crop to the offset feed opening. A floating, fixed-tine roller takes the crop over a stone trap and feeds tangentially to the 2.6 metre wide thresher (separator at the rear of the table) which is hyrostatically driven with an automatic torque sensing circuit for maintaining constant drum speed. Centrifugal action completes the separation of the crop which passes through a 360 degree grill and concave. Helical bars move the straw to the near side of the drum where it



exits via an auger and a swath deflector to the outside of the front drive wheel, but within the width of the header. The drum, feed roll and header can be reversed manually. With a new 300 hp version, the MX 300, a hydraulically powered straw chopper can be mounted on the end of the drum to chop and spread the straw to the side.

An auger takes the crop to the cleaning area in the body of the combine. There, contra-rotating distribution augers spread the crop before it falls into the de-awner and accelerating roller which propels the crop through a series of plates which

The Laverda MX 240 combine harvester

can be angled to the vertical by a pendulum device to compensate for slopes of up to 20% (1 in 5 gradient) so that the grain, trash and chaff is fed on to the cleaning shoe. An initial air blast removes much of the chaff and trash before the crop passes through the classic sieve system where a second air flow completes the cleaning.

Returns are directed to a six bar re-thresher mounted on the end of the distribution augers and then re-routed through the cleaning system. A large 7 ton capacity grain tank can be loaded in 100 seconds.

Four speed hydrostatic transmission is powered by a Fiat 14 litre engine delivering either 240 hp DIN, or 300 hp DIN in a turbocharged form, to ensure high capacity combining.

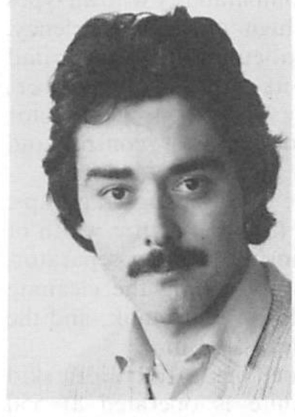
Operator environment is first class due to the cab having isolation mounting, air conditioning and ergonomically designed controls, most of which have electro-hydraulic action for quick, easy and reliable operation. Efficiency of operation is assured by numerous audible and visual alarms monitoring engine and functional components, and by the inclusion of grain loss monitors.

Phillip Bosworth is Product Manager of Hesston & Laverda equipment for Fiatagri Ltd.

Developments in solar grain drying in Scotland

H B Spencer and R Graham

H B Spencer



R Graham

Summary

THIS paper presents some results of grain drying trials carried out over a number of years in a solar-assisted drying barn.

The energy savings due to utilisation of the solar energy available at the time of drying are given together with initial assessments of the economic benefits likely to be achieved using a solar-assisted dryer.

Worthwhile energy savings are achievable through reduction in fan running times, but to obtain a reasonably short payback period the use of this dryer must be extended over the whole of the Summer/Autumn season by drying hay crops as well as Winter and Spring sown cereals.

1. Introduction

Often the cereal grain harvested in the UK is at too high a moisture content for safe storage. About two-thirds of the grain dryers use near ambient air to dry the grain. These types of drier, often storage driers, present opportunities for the collection of natural low intensity solar radiation, over large areas, for raising drying air temperatures by small amounts.

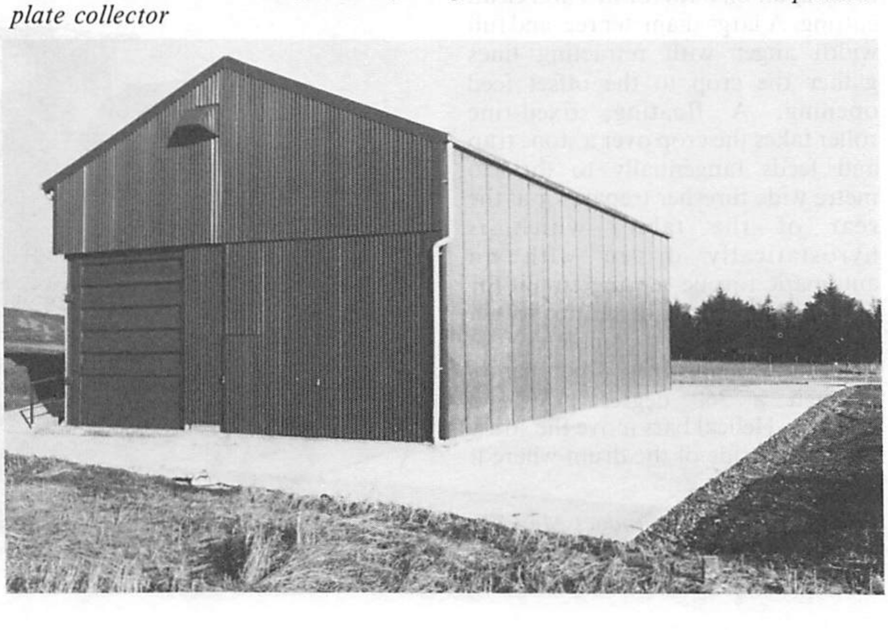
The economic benefits from collection of such energy are the saving in fuel costs of supplementary heaters, when used, or the reduction in fan running times if only ambient air is used.

Experiments and simulations in the USA (Shove 1977) have given uncertain conclusions; a general problem was drying to an unnecessarily low moisture content, especially in regions with a dry climate. Fraser and Muir (1980) calculated costs for several Canadian locations and showed benefits could accrue in comparatively humid climates of Ontario.

The SIAE solar barn (Ferguson and Bailey 1981) was built with the aim of investigating the feasibility of solar-assisted drying in Scotland. Constructed in 1980 (fig 1), the barn has been used to dry hay and grain crops successfully in every subsequent year; in the wet Summer of 1985 it appeared that the only worthwhile hay in the region was produced with the solar barn.

The results of the trials over this period have demonstrated the possible energy savings for both hay and grain drying under large scale conditions. The data gained can be used for assessing likely economic benefits, for example by installing simple solar collectors for small temperature rise drying applications. For comprehensive assessment

Fig 1 Solar barn showing south facing wall with Filon covered suspended plate collector



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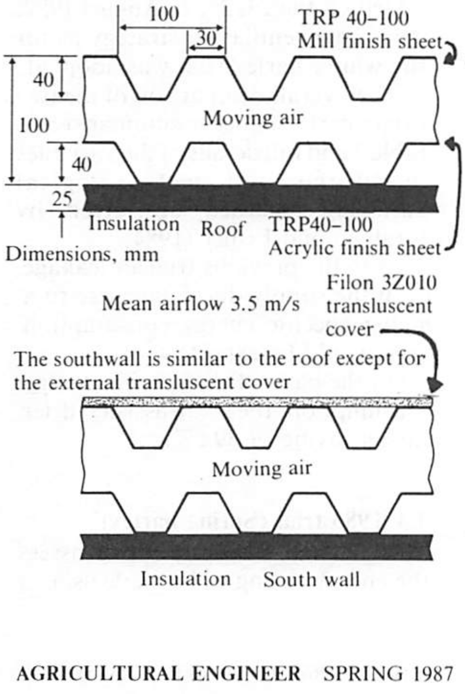
of potential economic benefits, various scenarios need to be considered taking account of such factors as fuel price inflation, material price inflation, grain prices, and the role of solar-assisted drying as an insurance policy against poor seasonal weather conditions. For example, the provision of the drying barn enabled hay to be produced from 45% wb material during the disastrous summer of 1985; in one such season the cost of the materials used for the solar collector could be recouped entirely. This illustrates the pitfalls associated with making simplistic economic studies of the benefits to be gained from such installations; much depends on the risks individual farmers are willing to take and on future energy costs.

2. Description of solar barn

A major requirement of the experimental barn design was a provision for undertaking comparative experiments between solar-assisted and ambient (or supplemented-heat) drying. A cutaway diagram of the barn, shown in fig 2, shows the two halves of the barn, a west and east section. The west side is the one usually used for solar-assisted drying. This takes air that has been drawn over the solar collectors on the barn's roof and south facing wall (fig 3).

Much of the energy received at the site is diffuse and while the north facing slope of the roof was not expected to be efficient at collecting direct radiation it was considered worthwhile to examine its

Fig 3 Construction of roof collectors (top) and south wall collectors (bottom)



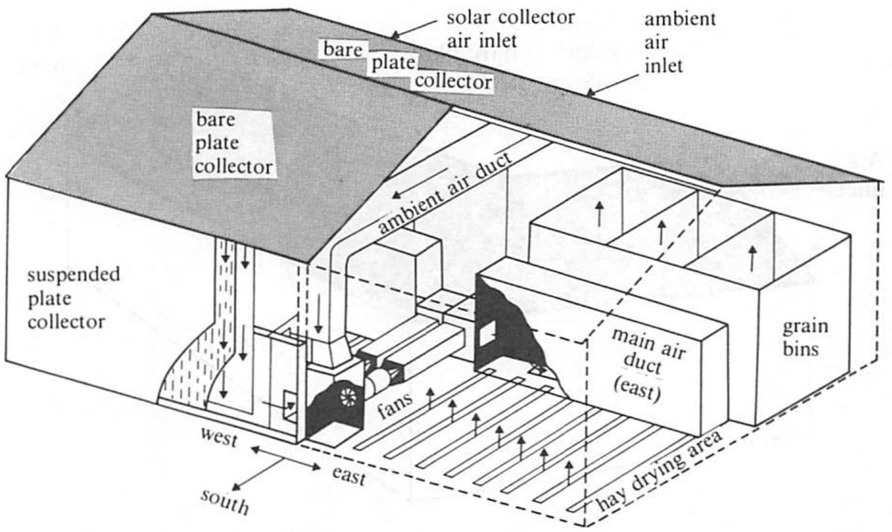


Fig 2 Constructional features of SIAE solar barn

effectiveness as a diffuse collector. Both faces of the roof were designed as bare plate collectors and the south wall was designed as a suspended-plate collector with air passing over both surfaces of the collector.

The fans were selected primarily for grain drying and, as such, the flow rates used when drying hay are well below the usual recommended rates. The air can be ducted to various parts of the barn and supplementary electrical heaters have been installed just downstream of the fans to provide additional heat for experimental studies.

Although the collector surfaces used in the SIAE solar barn make use of aluminiun cladding and a Filon transluscent cover for the suspended plate collector (fig 3), other constructions are possible, almost all of which are within the capacity of farm labour. A Swedish example of such a construction is shown in fig 4.

For experimental research purposes the SIAE Solar Barn uses an LSI 11–2 microcomputer for control, data acquisition, and recording. Temperatures, humidity, and weather conditions are logged every 15 mins. The computer can also be used to study various control algorithms; in general these switch off the fans when the drying potential is low. In the case of hay drying the algorithms also monitor crop temperature to sense any excessive rise during fan-off conditions. Details of the system are given by Fisher and Duncan (1985).

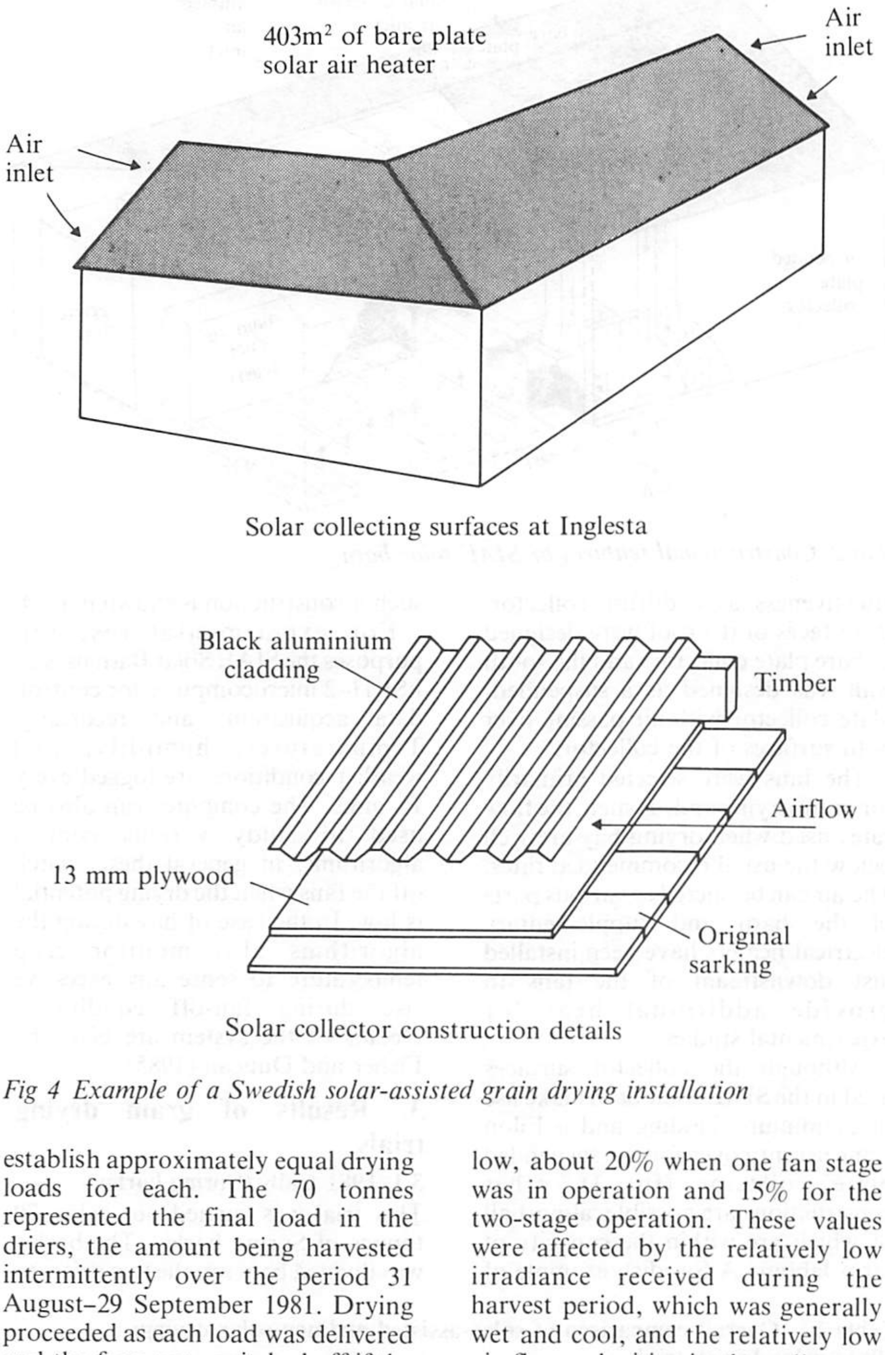
3. Results of grain drying trials

3.1 1981 trails (Spring barley)

This trial was carried out using 70 tonnes of Spring barley. The barley was divided between the two driers to

Table 1. Overall comparison of solar-assisted and non-solar drying: 1981 spring barley trial

	Solar-assisted	Non-solar
Mean initial wb mc, %	18.60	18.60
Mean final wb mc, %	13.95	15.07
Final mass of grain, kg	33260	33690
Final mass of dry matter, kg	28620	28620
Ventilation time:		
one fan stage, h	229	211
two fan stage, h	138	218
Mean ventilation rate:		
one fan stage, m^3/s	1.92	2.18
two fan stage, m^3/s	3.29	3.29
Mean power consumption, kW	7.68	8.43
Fan consumption, kWh	2817	3615
Adjustment for bypass duct loss, kWh	—	989
Total energy consumption, kWh	2817	2626
Specific energy consumption, MJ/kg moisture removed	5.11	6.44



Solar collecting surfaces at Inglesta

Solar collector construction details

Fig 4 Example of a Swedish solar-assisted grain drying installation

establish approximately equal drying loads for each. The 70 tonnes represented the final load in the driers, the amount being harvested intermittently over the period 31 August–29 September 1981. Drying proceeded as each load was delivered and the fans were switched off if the grain had dried at the surface prior to further loads being received. This process would be typical, as was the case in this trial, where the weather dictated the drier loading pattern. Table 1 summarises the results of this trial. Full details of the meteorological variables recorded and their variation during the trial are given by Graham (1983). An adjustment to the energy consumption of the non-solar drier was necessary to account for the incidental energy transfer from the internal building environment to the bypass duct providing the ambient air intake.

The solar collector efficiencies achieved in this trial were relatively low, about 20% when one fan stage was in operation and 15% for the two-stage operation. These values were affected by the relatively low irradiance received during the harvest period, which was generally wet and cool, and the relatively low air flow velocities in the collectors; even so shorter overall fan running times were achieved by the solar-assisted drier.

3.2 1982 trial (Winter barley)

This trial compared the performance of the solar-assisted drier and a conventional drier in a direct manner by using electrical heat supplement to the non-solar drier to give the same drying potential as the solar-assisted drier. This also enabled the electrical power consumption equivalent to the solar gain to be determined easily as the drying times for the two driers were then virtually identical. The driers were loaded by splitting the load on 4 August 1982, the trial being completed by 12 August.

The ventilation was controlled so that the fans were switched off for a period of 1 h if the input air relative humidity to the solar assisted drier exceeded 78%. After 1 h switch-off the fans were run again for 5 min to obtain a further check on relative humidity. The electrical supplement to the non-solar drier was switched automatically to match the integrated relative humidity over a 5 min period of the air input to the solar drier.

In this way the final mean moisture contents of the bins were approximately equal after identical ventilation times. Full details of the trial and the meteorological variables are given by Graham and Fisher (1983). The results from the trial are summarised in table 2.

The final moisture contents were slightly lower than would be necessary for safe storage and the specific energy consumption for the solar-assisted drier was somewhat higher than for conventional ambient air driers, but this was attributed to a leaking air duct between the collectors and the drier.

On the basis of specific energy consumption, the solar-assisted drier gave a saving of 48.1%.

3.3 1982 trial (Spring barley)

The aim of this trial was the same as the previous trial carried out using Winter barley. The same strategy was adopted of supplying electrical energy to the non-solar side equivalent to the solar gain.

The drier was loaded on 12/13 August 1982 with Spring barley, the grain being divided equally between the two driers. Further loads were added on the 23, 25, 26 August 1982. The same ventilation strategy as for the winter barley trial was adopted.

The overall comparison of the two driers performance is summarised in table 3 and full details of the variables monitored and meteorological variables recorded are given by Graham and Fisher (1984).

As in the previous trial air leakage from the supply ducts gave rise to a higher specific energy consumption than would be expected.

On the basis of the specific energy consumption, the solar-assisted drier gave a saving of 39.5%.

3.4 1983 trial (Spring barley)

This trial was carried out to assess the energy saving to be made using a

Table 2. Overall comparison of solar-assisted and electrically supplemented non-solar drying: 1982 winter barley trial

	Solar-assisted	Electrically-supplemented
Mean initial wb mc, %	22.0	22.0
Max initial wb mc, %	25.8	25.8
Min initial wb mc, %	19.2	19.2
Initial mass of grain, kg	10350	10350
Initial dry matter content, kg	8071.5	8071.5
Mean final wb mc, %	13.6	13.4
Max final wb mc, %	14.5	13.8
Min final wb mc, %	13.0	13.0
Final mass of grain, kg	9339	9319
Ventilation time, h	183.25	183.25
Ventilation rate, m^3/h	2.74	2.61
Fan rating, kW	11.20	11.04
Fan consumption, kWh	2053	2023
Electric heater consumption, kWh	0	1296
Adjustment for incidental gain, kWh	0	713
Total energy consumption, kWh	2053	4032
Specific energy consumption, MJ/kg moisture removed	7.29	14.05
Specific energy consumption, kWh tonne wet grain^{-1} % moisture removed^{-1}	23.45	45.03

Table 3. Overall comparison of solar-assisted and electrically supplemented non-solar drying: 1982 Spring barley trial

	Solar-assisted	Electrically-supplemented
Mean initial wb mc, %	22.0	22.0
Max initial wb mc, %	26.1	26.1
Min initial wb mc, %	17.9	17.9
Initial mass of grain kg	34756	35145
Initial dry matter content kg	27125	27424
Mean final wb mc, %	14.4	14.1
Max final wb mc, %	16.0	15.0
Min final wb mc, %	13.0	13.1
Final mass of grain, kg	31673	31913
Ventilation time h, 1 fan stage	250.9	250.9
Ventilation time h, 2 fan stages	402.2	402.2
Ventilation rate, m^3/s:		
1 bin, 1 fan stage	0.62	0.59
1 bin, 2 fan stages	0.88	0.88
2 bins, 2 fan stages	1.67	1.86
Air flow produced by fan, m^3/s:		
1 bin, 1 fan stage	1.86	1.77
1 bin, 2 fan stages	2.61	2.46
2 bins, 2 fan stages	3.09	3.19
Fan consumption, kWh	6029	6001
Electric heater consumption, kWh	0	3098
Adjustment for incidental gain, kWh	0	1351
Total energy consumption, kWh	6029	10450
Specific energy consumption, MJ/kg moisture removed	7.04	11.64
Specific energy consumption, kWh tonne wet grain^{-1} % moisture removed^{-1}	22.82	37.64
Specific energy consumption, kWh/kg moisture removed	1.96	3.23

ventilation strategy which consisted of:

(a) continuous ventilation until surface moisture content reached 20% wb

(b) thereafter, ventilation during daylight hours only until surface moisture content reached 15% wb

This drying strategy was adopted for both the solar assisted and ambient air driers. The driers were loaded with Spring barley on 29–31 August and 5 September 1983, the grain being divided equally between the two driers.

The results from the trial are summarised in table 4 and fuller details are given by Graham (1985).

Mean solar collector efficiencies were: 1st fan stage 24 .1%, 2nd fan stage 46.4%. On the basis of specific energy consumption the solar-assisted drier gave a saving of 24.4%.

4. Economics of solar-assisted drying

4.1 Costs and payback periods for SIAE solar barn

A preliminary economic study was carried out using the trial results and data on the barn's construction. It was assumed that the barn is fully utilized for drying hay, winter and spring cereals, and not just for a spring or winter sown cereal crop. Obviously by making maximum use of a capital investment the best economic returns are likely. In such studies the payback period is a crude but frequently used measure for deciding if an investment is worthwhile. Some industrialists often only consider investments with payback periods not exceeding 2–3 years. Maybe farmers can consider longer periods but any payback period over 5 years is likely to have limited attraction. A comprehensive economic assessment requires the use of discounted cash flow techniques which could lead to different conclusions.

The 1985 costs presented below represent the additional costs incurred in fitting the solar collector to a barn of similar type and dimensions to the SIAE barn.

	£
Cladding	
320 m² of mill finish aluminium cladding £7.92/m²	2534
Glazing	
100 m² of 'Filon' £4,54/m²	454
Other	
ie. rivets, bolts, sealant, separators etc.	750
less cost of ambient air duct	-125
Total (not including labour)	3613
Labour	
8 man-weeks (320 man-hours) £6.00/h	1920
Total	5533

Table 4 Overall comparison of solar-assisted and non-solar drying: 1983 Spring barley trial

	Solar-assisted	Non-solar
Mean initial wb mc, %	21.1	21.1
Max initial wb mc, %	24.8	24.8
Min initial wb mc, %	18.4	18.4
Initial mass of grain, kg	19680	19680
Initial dry matter, kg	15518	15518
Mean final wb mc, %	12.9	14.9
Max final wb mc, %	14.4	15.8
Min final wb mc, %	11.5	14.3
Final mass of grain, kg	17815	18234
Ventilation time, h, 1 fan stage	148.2	148.2
Ventilation time, h, 2 fan stages	235.4	253.2
Ventilation rate, m^3/s:		
1 bin, 1 fan stage	0.58	0.61
1 bin, 2 fan stages	—	—
2 bins, 2 fan stages	—	—
Air flow produced by fan, m^3/s:		
1 bin, 1 fan stage	1.51	1.45
1 bin, 2 fan stages	2.38	2.41
2 bins, 2 fan stages	3.02	3.40
Fan consumption, kWh	3508	3723
Adjustment for incidental loss from by-pass ducts, kWh	0	-125
Total energy consumption, kWh	3508	3598
Specific energy consumption, MJ/kg moisture removed	6.77	8.95
Specific energy consumption, kWh tonne wet grain % moisture removed $^{-1}$	21.74	29.49

The South of Scotland Electricity Board charge for farm use of electricity is 4.12 p/kWh for a bimonthly consumption exceeding 4000 kWh; this figure will be taken as a representative energy cost.

It is assumed that the barn is used as efficiently as possible during the period in which crop drying occurs (July through early October). The barn is expected to be operational for 90% of this time. The efficiency of the solar collector is approximately 40%.

Taking the above into consideration an annual saving of 16.6 MWh may be expected in an average year. This represents a financial saving of approximately £680. The payback period for the solar barn in its present form and mode of use would then be:

Using farm labour	6 years
Using contracted labour	9 years

There are two additional economic factors that these calculations do not take into account:

(i) Results obtained so far indicate that solar dried hay has a greater marketable and feed value due to slightly higher 'D'-values;

(ii) The solar collector provides an 'insurance' value, in that during years with particularly unfavourable weather conditions a solar barn will be capable of drying a crop which could not be dried successfully without additional heat and in such years benefits will be greater than usual.

4.2 Increased efficiency and utilisation

4.2.1. Improved use of collectors.

The various surfaces of the solar collector are most at different times of the year. Thus the south wall captures a much higher proportion of the total solar input during spring, autumn and particularly winter, while the roof is most effective at the height of summer. If the barn is to be used solely in the summer and early autumn then the payback period will be reduced if the wall collector is eliminated.

An alternative to this approach is to consider that the reason why the profitability of the solar barn is at present marginal, is that it is used for only a short period of the year. Further, it is not used during the month of June when the solar input will be at its peak. Different uses for the barn are therefore needed for the spring and possibly winter. Consideration should be given to use for preheating animal houses and greenhouses and for drying additional crops, such as lucerne and timber.

Lucerne is considered to be suitable for growing in certain parts of Britain but when the crop is dry the leaf is brittle, and is therefore subject to losses through field operations such as turning. There is a distinct possibility that with solar drying, lucerne production may be feasible. The crop may be brought in, in a wet state and dried quickly and cheaply. The benefits would be threefold:

(i) Availability of excellent fodder material,

(ii) Reduced nitrogenous fertilizer cost,

(iii) Beneficial environmental impact (lower levels of fertilizer).

Timber is a crop for which value increases dramatically when dried (typically from £30/tonne to £1000/tonne). Current practice is to dry wood in specifically designed kilns. Should a future analysis prove conclusive, where applicable, solar barns may be designed so as to be convertible to solar kilns in the months where crop drying is not practised. It is also anticipated that solar kilns (with no field crop drying facility) will be a viable economic prospect. Further, it may be expected that the end product will be of a high quality due to the slow drying rate and the diurnal temperature change which will relieve stresses in the wood.

4.2.2. Alternative systems.

There are presently on the market, solar collectors for which efficiency is claimed to be greatly superior to that of the collector presently in use on the solar barn. For one such collector, the manufacturers claim an efficiency of 80% at a slightly cheaper cost. Such a collector would dramatically reduce the pay-back period.

An alternative approach would be to simplify drastically the design of the solar collector. For instance, the collector channel may consist of an absorbing layer of aluminium cladding, with the inner layer made of asbestos cladding. The cost of such a collector would be considerably lower than that of the present system.

However no data are yet available as to the performance of such a collector and an analysis or trial would need to be carried out before any conclusions were advanced.

Once the air has passed through the crop its temperature has decreased whilst its moisture content has increased; however, the temperature of the air is still above ambient. There are two methods envisaged for recouping this energy, both of which would require analysis to determine economic viability.

(a) Fitting heat exchangers (and heat pump). Energy withdrawn from exhaust air would be recirculated to the incoming air stream.

(b) Channelling exhaust air directly to other installations, eg. piggeries, glasshouses. The viablility of this will depend on many variables, the crucial one being the proximity of the two installations. A further possibility would involve building a heat store (most likely of the rock storage type). During periods when the barn is not in use the fans will keep running and the captured solar energy will be transferred to the heat store. When crops are being dried this stored energy will be retrieved, thus increasing the heat input when it is needed. Again this requires careful analysis.

4.2.3 Possible overall potential energy savings for Scotland

From the data obtained during experiments, it has been established that for systems similar to the SIAE barn, the overall energy savings to be expected are:

Cereals	30%
Hay	50%

Cereal production in Scotland is about 2 million tonnes, 75% of which is dried in store; if all of this were dried using solar-heated air, an annual energy saving of 95 GWh would be realized, corresponding to a cost saving of £3.9 m.

As yet there are no statistics available for total Scottish hay production, but if we assume that the solar grain drying facilities were used in a manner similar to that at SIAE under average meteorological and field conditions this would provide 0.4 m tonnes of hay drying capacity; the annual energy and financial savings would then be of the order of 48 GWh and £2.0 m respectively.

Therefore, for cereals and hay, solar drying would represent a total potential saving of £5.9 m. This does not take into account the other uses of the solar collector mentioned above; including these the savings would be considerably greater, though at this stage we can only speculate as to the magnitude. Neither does it take into account the costs of additional cladding and equipment required for the solar barn (see paragraph 4.1).

5. Conclusions

From an economic point of view the prospects for the barn appear to be marginal at present. However a simplified analysis indicates that solar drying of crops in Scotland could be a viable proposition in suitable cases. Further, with the knowledge gained from building the barn as well as understanding of the processes involved in solar energy, future designs will have greater economic potential.

The successful use of solar energy will be very dependent on the future trends of energy prices. It is not the purpose of this report to predict these trends, though it will be noted that present sources of energy are limited and the real cost of energy is still expected to rise over the longer term. At present prices there is a potential saving of approximately £6 m from providing solar assistance in grain and hay drying in Scotland. Should the solar collector systems be well integrated with other viable farm activities, this saving could be much greater, and possibly double.

Finally, one problem to be overcome is the general belief that solar energy cannot be exploited satisfactorily in Scotland due to the northern latitude; the case for solar energy needs convincing presentation to demonstrate the greatest potential gains correspond to the greatest need to supplement ambient conditions.

Acknowledgements

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What is Quality Assurance and what do we need to do about it?

I J Duncan

Introduction

WE all know that, during the past decade British manufacturing industry has fallen to a very low level of production in terms of manufactured goods sold throughout the world. The same trend has affected much of the agricultural machinery manufacturing section of industry.

Success in world markets has always depended upon a supplier's ability to satisfy customers on non-price factors, as well as on price. A main non-price factor is quality, and this can be defined as the fitness of a product to meet the customer's expectations throughout its useful life. These expectations can include good design, reliability, safety, ease of maintenance, economic energy consumption and acceptability in environmental terms, and some of these considerations will also be regulatory requirements. In planning to provide for these expectations, it is often helpful to suggest certain levels which will be acceptable to customers, and these can be agreed in the form of standards. National standards are usually easiest to formulate, because comparatively fewer people are involved in the discussion, but international standards are of more use when goods are made to be sold overseas.

Governmental initiatives

It seemed safe to assume that if the quality of British made products could be improved economically, then it would be possible to increase acceptability, and therefore sales of these goods at home and overseas. The Government decided to suggest ways in which this result could be achieved, and in 1983 published a White Paper on "Standards, Quality and International Competitiveness". The White Paper outlined four ways in which the Government is taking the initiative and these are as follows:—

Firstly, a Memorandum of

Understanding between the Government and the British Standards Institution (BSI) was drawn up, whereby the latter is required to modify and improve the standard making procedures.

Secondly, the Government is to encourage regulatory bodies to express their technical requirements by reference to British Standards as the national embodiment of sound modern practice. This is important in areas such as industrial and consumer safety which are controlled by the Health and Safety at Work Act and the Consumer Safety Act.

Thirdly, the Government agrees to make greater use of standards in stating its' purchasing requirements, and to encourage other public purchasers to do the same. Progress with this intention is apparent, although not all Government Departments have themselves accepted this concept.

Fourthly, the Government lays down that standards can be made more effective in application by proper quality assurance and certification schemes.

The White Paper and the Memorandum of Understanding have led to a National Quality Campaign launched recently by the Secretary of State for Trade. To assist this campaign, Government Departments are acting as follows:—

(i) The Department of the Environment is continuing consultancy funding of draft codes of practice in the areas of civil engineering and building, and currently spending £130,000 per annum.

(ii) The Property Services Agency is to purchase to British Standards and to use Kitemark schemes. They have recognised 65 existing schemes, and BSI is examining some 130 standards either to revise them or to include additional items.

(iii) The Department of Trade is making available £250,000 for consultancy drafting of standards each year, and is funding travel to international meetings by certain delegates up to £400,000 annually. It will also spend a considerable sum of money to support new quality schemes as part of the National Quality Campaign.

(iv) The Department of Industry has its Focus Committee on Information Technology where the ultimate objective must be international standards. The increased use of BSI drafts for Development is planned, and the costs of delegates to international meetings on information technology will be met. In co-operation with the Design Council, a Design for Profit campaign has been introduced. This Department is supporting the National Quality Campaign by allocating up to £8,000,000 to fund schemes for small companies who are prepared to improve their quality management systems.

(v) The Government announced a new scheme for national accreditation of certification bodies, such as BSI, to give the UK certification systems greater prestige in the home and overseas markets. Products can be inspected on a sampling basis, and a certificate issued stating that the product, or at least a representative sample actually conformed to the nominated standard.

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Quality assurance

The foregoing seems to be a logical progression of measures designed to help industry to help itself, and the main thrust of the campaign is developing in the field of quality assurance. In the area of agricultural machinery manufacturing, the Agricultual Engineers Association (AEA) and BSI are co-operating in overhauling the UK standard making procedures, and the AEA is seeking to do the same in Europe through similar representative organisations. This industry has always relied heavily on international standards, and progress in this area must be maintained or improved. With these initiatives already in motion, what should be our view of quality assurance?

If it is accepted that the objective is to increase sales by maintaining an already high quality of product, or by improving economically the quality of existing or proposed products, this can be achieved by the use of already well-known basic management precepts. It is obvious that clear management objectives based on good marketing objectives are needed, and that specifications must be comprehensive and unambiguous. Design must be simple — it is often too easy to make it complicated! — and there must be effective control of production which should include testing and checking reliability. There must also be some regular procedure for review of design, based on feed-back from customers and service trades, and control of quality in purchasing bought-in products is very important.

All of these considerations, as well as a number of others, are set out clearly in British Standard 5750 — Quality Systems. This standard, as well as BS 4778 — Glossary of Terms used in Quality Assurance (including reliability and maintainability terms), BS 4891 — A Guide to Quality Assurance, BS 5233 — Glossary of Terms used in Metrology, BS 5760 — Reliability of Systems, Equipment and Components, BS 5781 — Measurement and Calibration Systems and BS 6143 — Guide to the Determination and Use of Quality Related Costs are included in a a hard-back book produced by BSI entitled — BSI Handbook 22 : 1983 — Quality Assurance which is obtainable from the British Standards Institution.

Clearly some of the techinques suggested in BS 5760 may be somewhat too sophisticated for basically a small batch production fabrication industry, but they can well apply to products such as bearings, shafts, brakes, and fastenings, which are supplied to the industry by sub-contractors. There is no doubt that if the precepts suggested are taken seriously, and put into practice, then both the intellectual and organisational aspects of management, as well as the full co-operation of the work force, must be completely involved.

Having bought the book and studied it, if it is decided that changes are to be made, how are these to be decided and financed? The Department of Trade and Industry will provide support in the form of 75% of the costs of up to 15 man-days consultancy, to help companies improve the quality and design of their products, or their manufacturing organisation or techniques, if they employ less than 500 persons. There is no charge for the first two days (which include preparation of terms of reference) and the remainder are charged at 25% of cost. If appropriate, it is possible to have advice involving five days or less on up to three separate enquiries dealing with short or medium term problems. Here again the first two days are free, and the remainder are charged at 25% of cost. If advantage is taken of this option, it is still possible to have further advice on a major project to complete the 15 man-days entitlement.

If, having listened to the advice, and having digested it, the decision is made to implement the scheme, guidance in this phase can be obtained from the Quality Assurance Services (QAS) of the British Standards Institution. This is a Division of BSI offering quality assessment, system assessment, product certification and inspection. Because of the range of its activities, QAS can put together a wide range of quality related packages, designed for the specific needs of a particular industry or customer. In the setting up of any new system, there is a learning curve, which can cost time and money, and with its experience of applying BS 5750, QAS claims it can reduce this cost to the very minimum. In addition, it is thought that the independent third party certification provided by QAS can be a positive boost to customer confidence in any quality assurance scheme. QAS has dealt with 318 new registrations based on BS 5750 during the past year, and a National Accreditation Council has been established. Further initiatives are expected regarding a national structure for the accreditation of certification activities including the formation of an Association of Certification Bodies. For instance the British Foundry Association has developed a quality assurance certification scheme in co-operation with Lloyd's Register Quality Assurance Certification Association Ltd.

The Department of Trade and Industry is issuing a series of leaflets resulting from the work of the Metrology and Standards Requirements Boards. These leaflets give the results of the Department's Metrology for Quality Demonstration Projects, and those issued so far are as follows:—

Metrology for Quality	1 —	In the wood working industry
Metrology for Quality	2 —	In the foundry industry
Metrology for Quality	3 —	In the textile colouring industry
Metrology for Quality	4 —	In the process machinery industry
Metrology for Quality	5 —	In the footwear industry
Metrology for Quality	6 —	A model of self help
Measurement in Britain	—	A framework for industry

Copies of these leaflets can be obtained from the Department of Trade and Industry.

Some companies have set up metrology centres, to attract business in measuring customers' products, and supplying equipment so that companies can carry out their own metrology. Such centres include computer controlled measuring machines, profile projectors, microhardness testers, etc. Accurate measurement and testing must be essential parts of checking the compliance with specification of many products, and the National Testing Laboratory Accreditation Scheme (NATLAS) has been set up to maintain, at an acceptable level, the quality of testing in the UK. The NATLAS Executive, which runs the scheme, is part of the National Physical Laboratory (NPL) in the Department of Trade and Industry. Like the British Calibration Service (BCS), NATLAS is an integral part of the national measurement system, and represents an important element of the infrastructure provided by Government to underpin the strategy for Quality and Reliability. Companies providing metrology centres or laboratories are assessed independently, and advice on policy is provided by the Advisory Council on Calibration and Measurement. Approved centres or laboratories are accredited to the NATLAS scheme and a list of such centres is available from DTI. On 1st October 1985, NATLAS and BSC merged, and formed the new National Measurement Accreditation Service (NAMAS) and it is hoped this move will result in greater consistency and economy of effort.

Quality circles

Finally, the importance of involvement of the work force cannot be understated, and one method of achieving this is the formation of "Quality Circles" (QC). The concept of QCs originated in Japan where quality becomes the responsibility of each individual who, with his or her workmates, is expected to apply individual and group skills to the problems facing them. This can harness the reservoir of ability, skill and experience often left untapped in Western industry and free first line and middle management for other tasks. Circles can be identified as properly trained groups of six to twelve persons, usually from the same working area, or doing similar work, who meet regularly in company time (say for one hour each week) under a trained leader, who is often a foreman or other first line supervisor. Their object is to identify and discuss problems which they encounter, obtain facts and data concerning these problems, and develop feasible solutions to them. Problems may relate to quality, productivity, safety, comfort, etc, but must not include wages, bonuses, etc. Some 350 UK companies are known to be operating QCs, and a National Society of Quality Circles was founded in 1982.

Conclusion

In defining quality, and in saying that it is one of the main considerations in making a purchasing decision, it is reasonable to assume that the maintenance, or improvement in, the quality of a product should lead to increased sales. The industry badly needs increased sales, and if these develop, then the UK employment position should be improved. Therefore, it also seems reasonable to assume that the industry should take action to implement some form of quality assurance scheme, and we hope that this paper has provided at least some of the necessary information.

A new facility for agricultural engineering education and machine test and development work

P F Hemingway

THE Engineering Department at Harper Adams Agricultural College has recently commissioned the construction of a covered soil working area.

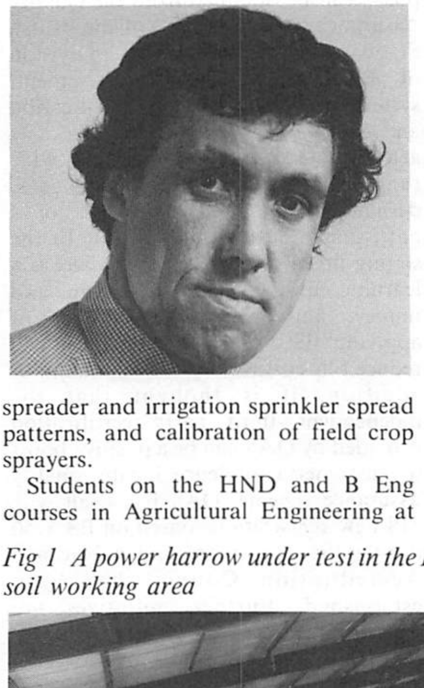
The fully clad building, the first of its type in the UK is of portal frame construction and stands over a sandy clay loam soil of the Rufford series. Measuring 60m x 30m the full area is free of any underground obstruction down to subsoiling depth.

Lighting is provided by transluscent panels in the south, west and east walls and northern half of the roof, augmented by thirty 400 W high pressure sodium lamps giving a light intensity of 500 lux at ground level if required.

Tractor exhaust fumes are removed by four ridge mounted extraction fans giving a possible 6 air changes per hour.

Irrigation is provided by five wall mounted sectoring sprinklers on either side of the building. These give the ability to irrigate the whole building, or either half at any one time. The opportunity thus exists to compare machine performance in dry soil with that in wet conditions. Rainwater is collected in a $26m^3$ holding tank, giving a maximum application of 14 mm over the whole area per full tank.

The building will be used for student demonstration of soil engaging implements such as ploughs and general cultivation equipment as well as grain drills, precision seeders and potato planters. Being fully clad, the building affords a 'still air' facility and so it will also be used for the accurate determination of inorganic fertiliser spreader and irrigation sprinkler spread patterns, and calibration of field crop sprayers.



Students on the HND and B Eng courses in Agricultural Engineering at Harper Adams will benefit greatly by having this facility on which to base investigational projects. These could typically involve study of machine component behaviour and soil movement for tillage tools or the study of soil compaction under varying tyre types and sizes.

It is also anticipated that machine test and development work will take place within the building in co-operation with the industry, either by collaboration with the recently formed Engineering Design Group at the college or by making the facility available to commercial organisations for their own staff to use. The isolation of the soil from the vagaries of the winter weather will enable such work to go on largely uninterrupted throughout the year.

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Fig 1 A power harrow under test in the Harper Adams Agricultural College covered soil working area