# THE AGRICULTURAL ENGINEER

Volume 41 Number 2 SUMMER 1986

The Institution of Agricultural Engineers

# Journal and Proceedings



THE AGRICULTURAL ENGINEER is published quarterly by the Institution of Agricultural Engineers
West End Road, Silsoe, Bedford MK45 4DU
Tel: 0525 61096

*Price £5.00 per copy, annual subscription £20.00 (post free in UK)*



*Front cover:*
*SIAE/Falcon straw incorporation and general tillage implement at work (Photo: SIAE)*

# THE AGRICULTURAL ENGINEER

**Volume 41 Number 2 SUMMER 1986**

## Contents



ISSN 0308-5732

# Tillage effects on growth, yield of maize and some soil properties — an experience at Dschang, Cameroon

E A Baryeh

## Summary

ABOUT half a hectare of land that had been mix-planted with cocoyam, maize and cabbage by a traditional farmer for several years followed by a four year fallow was utilised for raising four crops of maize for two years. The land was divided into plots of 20 m by 15 m. Some of the plots were left untilled, some were strip tilled and others were ploughed with a disc plough followed by disc harrowing. A 30 kW Russian tractor was used for the tillage processes. The maize was hand planted using cutlasses. All treatments during crop establishment were the same except the tillage treatment. The growth, yield and some soil properties were monitored.

In general, the ploughed plots had the highest yield in the first season but yield declined from 5.5 t/ha to 4.0 t/ha in the two years. Zero tillage exhibited a consistent yield of about 4.2 t/ha while the strip tillage increased from 4.0 t/ha to 4.6 t/ha. Crop height and leaf area trends were proportional to yield. Zero tillage showed the highest infiltration while conventional tillage and strip tillage showed high soil compaction. Soil moisture content was highest for zero tillage. Soil bulk density stayed around 14.5 kg/m$^3$ for zero tillage and strip tillage and around 14.2 kg/m$^3$ for conventional tillage.

## Introduction

Tillage is the art of mechanically loosening the soil to a convenient depth for plant cultivation. When the soil is not loosened and the seed or plant is introduced directly into it, this is termed zero tillage or no tillage. According to Boone *et al* (1980), Kuipers has identified four tillage systems based on the extent to which loosening effects are incorporated and compacting effects are tolerated in the soil. This is indicated in table 1 which shows that loose soil husbandry maximises the loosening effect and minimises compaction by reducing field traffic.

*Dr Edward Baryeh is Deputy Managing Director of BEAG Farming and Haulage, PO Box 8049, Accra, Ghana.*

*Refereed paper: manuscript received 28 August 1985 and accepted in revised form 2 February 1986.*

**Table 1 Tillage systems (Boone *et al* 1980)**

| | *Loosening effects* | *Compacting effects* | *Tillage system Kuipers' terminology* | *Usual termi-terminology* |
|---|---|---|---|---|
| 1 | + | — | Loose soil husbandry | Minimum tillage |
| 2 | + | + | Traditional tillage | Conventional tillage |
| 3 | — | — | Rational tillage | Zero tillage without heavy machinery |
| 4 | — | + | Zero tillage | Zero tillage with heavy machinery |

Conventional tillage, when properly done, breaks the compact upper soil surface, enhancing crop root development and making it easier for the roots to absorb water and other plant nutrients. It also allows soil moisture to seep deeper to areas where it can act as a reserve during dry periods. Tillage also serves as a weed control measure by inverting weeds and promoting their quicker decomposition and hence availability as plant nutrients. Tillage, however, has the disadvantage of compacting the soil over long periods of time and exposing the loosened soil to erosion. This compaction is partly due to the constant use of heavy farm equipment where mechanised farming is practised and partly due to wind erosion. In windy locations, top soil erosion of conventionally tilled fields leaves a more compact subsoil which usually contains less crop nutrients.

Zero tillage has the advantage of less soil compaction and of protecting the soil against erosion. The disadvantages tend to be the advantages of conventional tillage. Zero tillage without heavy machinery preserves the soil properties best but it is time consuming and limits the area which can be cultivated by a farmer.

In the study presented here, the effect on maize cultivation and some soil properties of three tillage practices have been evaluated over a period of two years at a location in Cameroon.

## Experimental procedure

The investigation was carried out in 1982 and 1983 near the campus of the University Centre of Dschang in

Cameroon. The land used had been mix-cropped with cocoyam, maize and cabbage by a traditional farmer for some years and fallowed for about four years. Mix-cropping is a common practice in the humid tropics whereby farmers plant two or more crops in the same field. Such crops are planted haphazardly. The land used had a 2° slope. The altitude of the area is 1500 m with rains spreading from March to October. The annual rainfall is 2600 mm. The climatic conditions at Dschang are well documented by Hawkins and Brunt (1965).

The soil is generally acidic (pH = 4.5) with some lava characterised by high organic matter content (Borris 1980). It comprises about 45% clay, 15% sand, 15% silt/loam and 25% concretionary stones up to a depth of about 40 cm (Borris 1980). The availability of phosphorus is about 40 kg/ha and that of nitrogen is 70 kg/ha (Borris 1980). Drainage is generally good. Bulk density is about 14.5 kg/m$^3$. The moisture content at field capacity is about 35 to 40% with a permanent wilting point of 15% at a depth of 0 -10 cm.

The land used for the investigation measured 95 m by 42 m. It was divided into 12 plots each measuring 20 m by 15 m with 0.5 m headlands between plots. The three tillage treatments namely: zero tillage, strip tillage and conventional tillage were randomly distributed over the 12 plots such that a completely randomised block experimental design was achieved.

All plots were hand cleared before tillage treatments. The cleared bush was left as mulch for the zero tillage and strip tillage plots. The strip tillage plots were tilled with chisels to a depth of 20–25 cm and a width of 10 cm at the beginning of each season. The conventional tillage plots were disc ploughed to a depth of 20–25 cm, with residue ploughed in, followed by disc harrowing at the beginning of each season. A 30 kW Russian tractor was used for the tillage operations.

Planting at 75 cm row spacing and 30 cm apart was done manually by students. The Institute of Agricultural Research, Cameroon maize variety Z–290 was used. This is a high yielding variety multiplied locally at the Institute.

Weed control was effected by hoeing by the same students. Hoeing was done two weeks, five weeks and eight weeks after planting. The crop was given 15:15:15 fertiliser a week after planting at 150 kg/ha and calcium-ammonium-nitrate at 50 kg/ha four weeks after planting or when the maize was knee high. Second season planting was interspersed at 1 m intervals with local white beans.

Crop height readings were taken at hoeing time and leaf areas were determined at tasselling time using a modification of Zuuring's (1975) model. At the end of each season, the yield was assessed at 14% moisture content (wb).

Infiltrometer and penetrometer readings were taken before the first tillage treatments and at the end of two years. A double cylinder infiltrometer was used. Penetration was measured with a 1.5 cm diameter steel rod, shaped like a cone at one end and flattened at the other end to receive impacts from a 50 N load through a height of 50 cm. Penetration was read on a vertical scale on the rod after a single impact.

Soil water content was determined gravimetrically in soil samples taken at depths of 15 cm, 30 cm, 45 cm and 60 cm at mid season. Average soil temperatures were taken at 10 cm depth with a mercury thermometer. The soil bulk density was measured within zero to 15 cm depth and 15 to 30 cm depth by taking soil samples with an auger, finding the oven dry weight and dividing this weight by the volume of the soil.

## Results and comments

The seed establishment and germination from observed stand counts were not significantly different from treatment to treatment. This could be due to the manual planting, the adequacy of rainfall at Dschang and the near absence of seed removal by birds and rodents.

During rain storms in the second season, when rains are often preceded by strong winds, the crops, on the conventional tillage plots exhibited 15 to 30% more lodging than those on the zero tillage plots. The crops on the strip tillage plots had about 5% more lodging than those on the zero tillage plots. The lodging occurred when the crop was more than 15 cm high. This could be due to the loose soil for conventional tillage and strip tillage and the absence of residue for conventional tillage. The residue can break the strength of the wind as the wind gets to the crop. This effect is more noticeable when the crop is not very tall. At greater crop heights, lodging was observed to be greatest for conventional tillage and least for zero tillage, suggesting that the height effect is about the same for all tillage treatments. Lodging did not affect growth and yield significantly except in situations where crops fell flat on the ground. Maize from lodged crops commonly weighed about 5% less than those on crops unaffected by lodging. Those falling flat on the ground produced unhealthy and lean maize. Lodging also affects yield because maize cobs on lodged crops are often missed during harvesting. Such crop which could adversely affect the results were eliminated from the analysis.

The average crop height, average leaf area per stand at tasselling time and the average yield are shown in tables 2 and 3 for the various seasons. These values are averages for the plots in each treatment. In the first two seasons, the conventional tillage plots produced the tallest crop, the highest leaf area and the highest yield. The zero tillage and strip tillage plots did not differ significantly from each other during the same period. This trend in the first year agrees with some results obtained in Senegal by Chopart (1983). During the first season of the second year, the crops for all the treatments did not vary significantly from each other. The crop following conventional tillage was, however, still poorer in growth and yield while that for strip tillage was better than the crop for zero tillage. In the second season of the second year, the crop for strip tillage had the highest height, leaf area and yield. The results for conventional tillage had dropped significantly in comparison with values for the first year. The results for zero tillage did not change significantly from one year to the next. These last results deviate significantly from Chopart's (1983) findings in Senegal where ploughing continued to increase crop yield. Working with soyabeans, however, Sidiras *et al* (1983) found that yields were always significantly higher under zero tillage and chisel plough treatments than in the conventional tillage treatment over a three year period. The decline in the growth and yield values for conventional tillage could be due to the deterioration and degradation of the soil due to erosion and the poor infiltration properties (fig 1). Leaving the residue on the soil surface in zero tillage and strip tillage constitutes a better residue management than ploughing it in and exposing the soil. This could have partly accounted for the trend displayed in tables 2 and 3. It may be noted that although the total yield over the two years is greatest for

**Table 2 Crop height, leaf area at tasselling and yield for 1982**

| Treatment | First season: Crop height, cm 1 | 2 | 3 | Leaf area, $cm^2$ | Yield*, t/ha | Second season: Crop height, cm 1 | 2 | 3 | Leaf area, $cm^2$ | Yield*, t/ha |
|---|---|---|---|---|---|---|---|---|---|---|
| Zero tillage | 42 | 135 | 185 | 5,050 | 4.2 a | 44 | 137 | 180 | 4,844 | 4.0 a |
| Strip tillage | 45 | 140 | 186 | 5,506 | 4.0 a | 42 | 137 | 183 | 5,458 | 4.2 ab |
| Conventional tillage | 50 | 147 | 196 | 6,500 | 5.5 b | 47 | 142 | 190 | 6,303 | 5.0 b |

*1 – First weeding; 2 – Second weeding; 3 – Third weeding*
**Means with common letters are not significantly different at 0.01 by Duncan's Multiple Range Test.*

**Table 3 Crop height, leaf area at tasselling and yield for 1983**

| Treatment | First season: Crop height, cm 1 | 2 | 3 | Leaf area, $cm^2$ | Yield*, t/ha | Second season: Crop height, cm 1 | 2 | 3 | Leaf area, $cm^2$ | Yield*, t/ha |
|---|---|---|---|---|---|---|---|---|---|---|
| Zero tillage | 40 | 145 | 190 | 5,272 | 4.3 a | 40 | 145 | 188 | 5,155 | 4.2 ab |
| Strip tillage | 42 | 147 | 192 | 5,600 | 4.5 a | 43 | 150 | 194 | 5,822 | 4.8 b |
| Conventional tillage | 40 | 138 | 190 | 5,485 | 4.2 a | 39 | 140 | 190 | 5,400 | 4.0 a |

*1 – First weeding; 2 – Second weeding; 3 – Third weeding*
**Means with common letters are not significantly different at 0.01 by Duncan's Multiple Range Test.*

conventional tillage, followed by strip tillage and then zero tillage, the fact that conventional tillage reduced steadily in yield over the four seasons, suggests that strip tillage and zero tillage are likely to produce better yield than conventional tillage over an extended period of cultivation. The tables suggest that some tillage improves yield. The strip tillage treatment showed a steady increase in yield with time while that for zero tillage stayed practically constant. The soil tends to compact with time probably due to erosion and some tillage loosens up the compacted top layer while incorporating some residue.

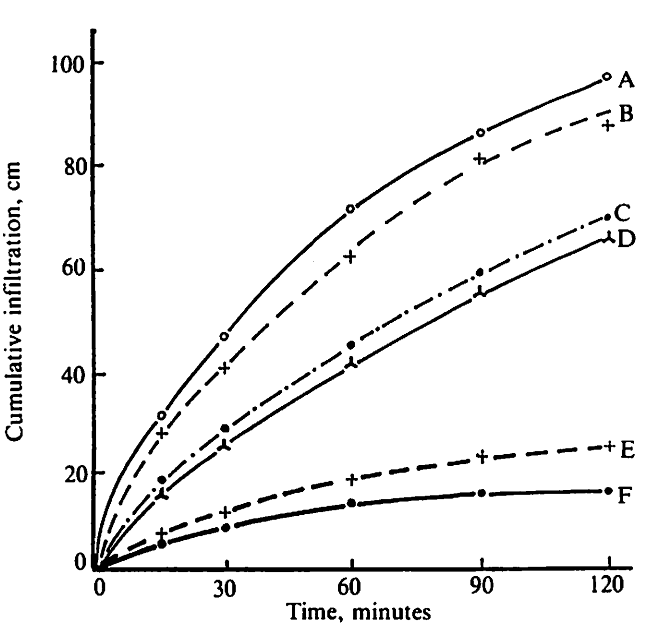



*Figure 1 Cumulative infiltration:*
*A – before cultivation; B – zero tillage (after two years); C – conventional tillage (along rows after two years); D – strip tillage (along rows after two years) E – conventional tillage (along tyre marks after two years); F – strip tillage (along tyre marks after two years)*

This then promotes water seepage, aeration and water retention, consequently improving root growth and yield. In the first season of 1982, the average yield for zero tillage and strip tillage did not differ significantly while conventional tillage showed a significantly higher yield. In the second season, the yield pattern had changed with zero tillage and strip tillage still showing no significant difference but this time strip tillage and conventional tillage also showed no significant difference. In the first season of 1983, all three treatments indicated no significant difference in yield, showing that zero tillage and strip tillage were improving in yield relative to conventional tillage. By the end of the second season of 1983, this trend was continued with strip tillage showing a significantly higher yield than conventional tillage. Strip tillage yield at this stage was also higher than that for zero tillage but the difference was not significant.

The cumulative infiltration observation is shown in fig 1 and penetration readings are shown in table 4. The infiltration was highest before tillage treatments. The

**Table 4 Penetrometer readings**

| Treatment | Penetration, cm: Before tillage | After tillage* | |
|---|---|---|---|
| Zero tillage | 7.0 | 6.5 | b |
| CV | 0.4 | 0.7 | |
| Strip tillage: | | | |
| along rows | 7.0 | 8.5 | a |
| along tyre marks | 7.0 | 3.0 | d |
| CV | 0.5 | 0.6 | |
| Conventional tillage: | | | |
| along rows | 7.0 | 5.6 | bc |
| along tyre marks | 7.0 | 4.2 | cd |
| CV | 0.5 | 1.1 | |

**Mean penetration values with common letters are not significantly different at 0.01 by Duncan's Multiple Range Test*
*CV = coefficient of variation*

reason for this is that when fields are fallowed, the soil is loosened due to the root development of the fallow scrub and the incorporation into the soil of organic matter from the scrub. At the end of two years, the cumulative infiltration for two hours for the zero tillage plots had fallen by only 9 cm. The infiltration for the strip tillage plots had fallen by 33 cm along the rows and by 84 cm along tyre marks. Infiltration for the conventional tillage plots had fallen by 29 cm between tyre marks and 74 cm along tyre marks. A high infiltration rate in zero tilled soil had also been found by Lal (1974) in some investigations in Western Nigeria. This trend was mainly due to the effect of less soil compaction, better soil structure and better pore space relationship in zero tillage systems. Lal (1974) explained that the high infiltration for zero tillage is in fact due to good soil structure, high porosity and minimal crustation problem. It is clear from fig 1 that the infiltration along the rows after two years is not very different for conventional tillage and strip tillage. This could be due to the fact that the soil loosening effects are similar along the rows in both treatments. From fig 1 and table 4, it is seen that soil compaction was generally high for conventional tillage. This could partly account for the decline in yield for this treatment. The compaction was high along tractor tyre marks for strip tillage. Since planting was not done along the tyre marks for this treatment, the yield did not decline. The results suggest that the use of heavy machinery should be minimised.

At the end of each season, it was observed subjectively that the plots with conventional tillage had suffered more erosion than the other plots. The low erosion on the zero tillage plots was due to their high infiltration, better soil structure and better pore space relationship. The plots had an infiltration rate of 2 cm/min within the first 15 minutes while they registered an average rate of 1 cm/min in the first hour. Lal, working in a Western Nigerian soil, also found this to be true. The residue on the soil surface in the zero tillage and strip tillage plots also account for the low erosion for these treatments by reducing splash and wind erosion and surface runoff during rainfall. Other contributing factors are the higher structural stability of the top soil layer for zero tillage and the increase in field capacity allowing more soil moisture retention. Soil structural stability was not measured quantitatively. Subjective observation, however, revealed the zero tillage soil to be more intact while the others showed a number of abrasions, cracks and dents. The difference in erosion between the various treatments probably would have been greater on land with a steeper slope.

Figures 2 and 3 show the variation of the soil moisture content with depth. The pattern did not differ much for

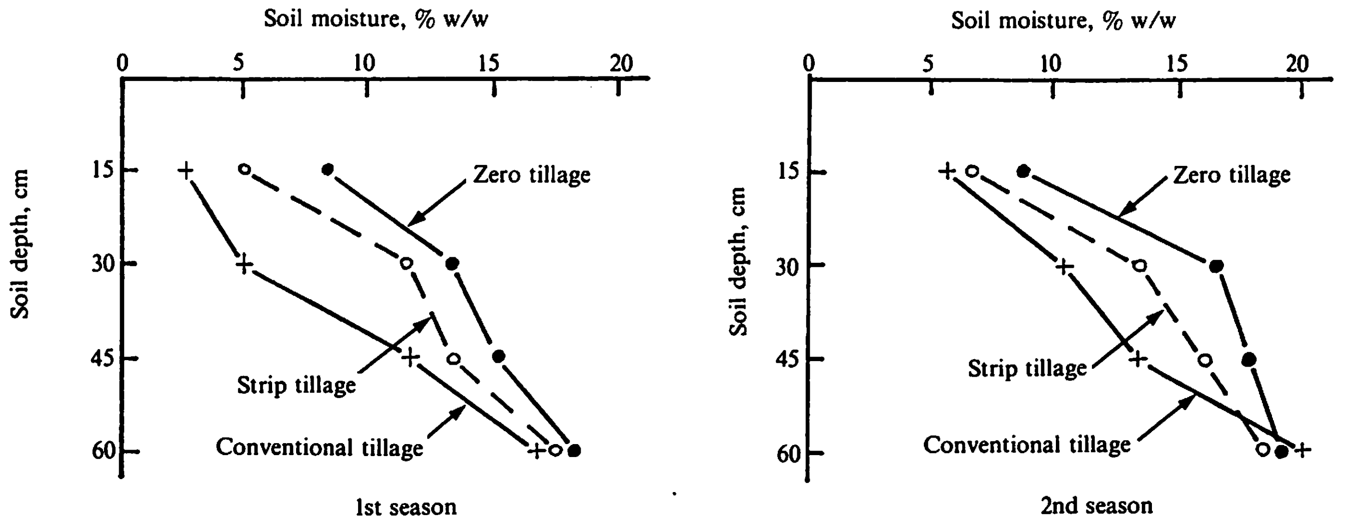



*Figure 2 Soil moisture variation with depth for 1982*

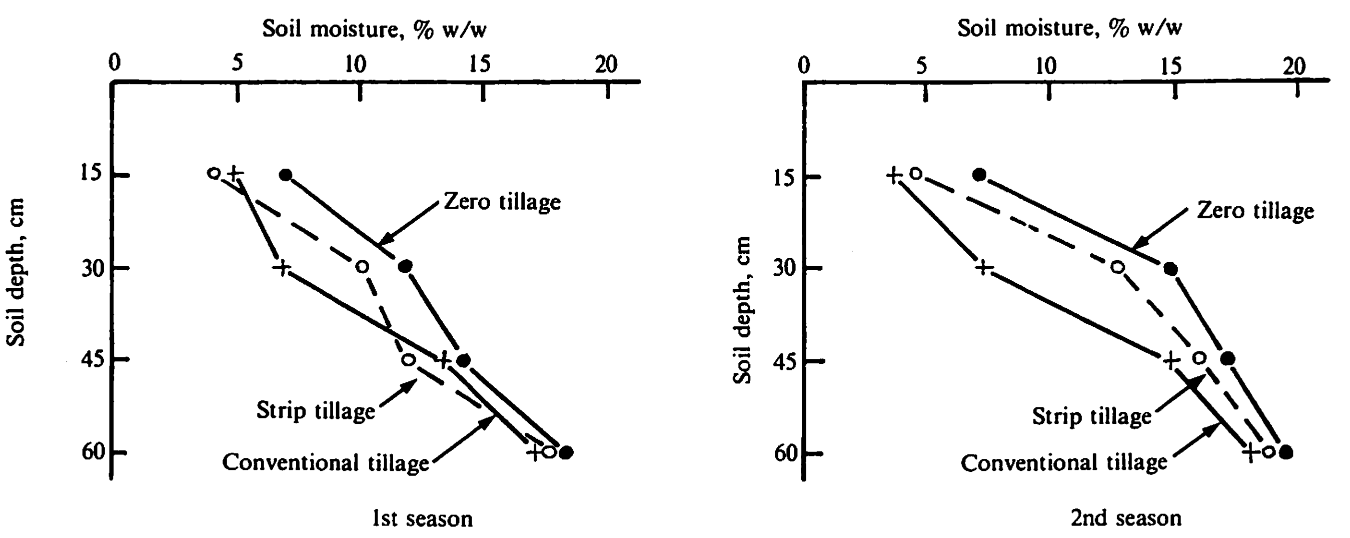



*Figure 3 Soil moisture variation with depth for 1983*

the seasons. The results showed that the zero tillage plots held more water than either of the other two treatments especially at depths of 0–45 cm. For example, at a depth of 30 cm, the average moisture contents in 1982 for zero tillage, strip tillage and conventional tillage were 15.0, 12.5 and 6.8% w/w, indicating that zero tillage and strip tillage, respectively, had 2.2 and 1.8 times as much water as conventional tillage. The corresponding average soil moisture content for 1983 were 13.3, 11.3 and 6.3% w/w, respectively, revealing that zero tillage and strip tillage and 2.1 and 1.8 times as much water as conventional tillage respectively. The standard deviation of the mean values of the soil moisture content was 0.03% w/w and the coefficient of variation 1.2% w/w. Sidiras *et al* (1983), working with soyabeans in Brazil in more clayey soil with similar pH value as the soil for this investigation, also found that soil water content in zero tillage fields were consistently higher than in conventional tillage fields. At 60 cm below the soil surface, the water content of all treatments did not differ appreciably for the various seasons. The water retention capacity of the zero tillage was highest up to about 50 cm depth, partly due to the residue on the soil surface and partly due to the fact that the soil structure was less disturbed. At deeper layers, the loose soil effect of conventional tillage was reduced improving the water retention quality of the soil for this treatment.

The average soil temperature did not vary significantly between treatments. In general, temperatures for strip tillage and conventional tillage were 1°C and 1.5°C lower than that of zero tillage respectively. This may be due to the extra aeration resulting from the soil loosening effect of the tillage.

Between 0–15 cm depth, the dry soil bulk density for zero tillage, strip tillage and conventional tillage were 14.7, 14.8 and 14.2 kg/cm$^3$ respectively. The respective values for a depth of 15–30 cm were 14.5, 14.6 and 14.3 kg/cm$^3$. The low bulk density for conventional tillage could be due to the residue which was ploughed into the soil but the differences between treatments were not significant. It has, however, been mentioned earlier on that zero tillage has a significantly higher infiltration and soil water retention ability than strip and conventional tillages. This indicates that the infiltration and the soil water retention characteristics of the soil around Dschang do not depend on the soil bulk densities. Other soil characteristics mentioned earlier therefore affect the infiltration and water retention characteristics.

## Conclusions

The results indicated that zero tillage and strip tillage are likely to have stable and increasing yields, respectively, over an extended period of cultivation. Conventional tillage on the other hand, is likely to give declining yields compared to its first year performance in the Dschang area as well as serious soil structure degradation and erosion with time. It is suggested that some minimum amount of tillage such as chisel or strip tillage is necessary for increased and sustained production. The precise level of minimum tillage for optimum yield and good soil properties, however, requires further investigation.

## References


**Boone F R, Krammer P H, van Eidet J** (1980). Experiences with three tillage systems on a marine loam soil I: 1972–1975. Agricultural Research Report No 899. Centre for Agricultural Publishing and Documentation, Wageningen, Holland.

**Borris N** (1980). The soils in and around Dschang. Unpublished mimeograph. University Centre of Dschang Library.

**Chopart J L** (1983). Effects of ploughing and minimum soil preparation in Senegal, Ivory Coast and Togo. *In*: Akobundu I O, Deutsch A E (Editors). No tillage crop production in the Tropics. International Plant Protection Centre, Oregon State University, Corvallis, USA.

**Hawkins P, Brunt M** (1965). The soils and ecology of West Cameroon. Expanded Program of Technical Assistance. FAO, Rome, Italy.

**Lal R**. Zero tillage implications to tropical soils. Unpublished mimeograph, International Institute of Tropical Agriculture Library, Ibadan, Nigeria.

**Lal R** (1974). No-tillage effects on soil conditions and maize-maize production in Western Nigeria. *Plant and Soil*, **40**, 321–331.

**Sidiras N, Derpsch R, Nondardo A** (1983). Effect of tillage systems on water capacity, available moisture, erosion and soyabean yield in Parana, Brazil. *In*: Akobundu I O, Deutsch A E (Editors). No-tillage crop production in the tropics. International Plant Protection Centre, Oregon State University, Corvallis, USA.

**Zuuring H R** (1975). Indices for the rapid early selection of Populus clones. PhD thesis (unpubl). Iowa State University, Ames, Iowa, USA.

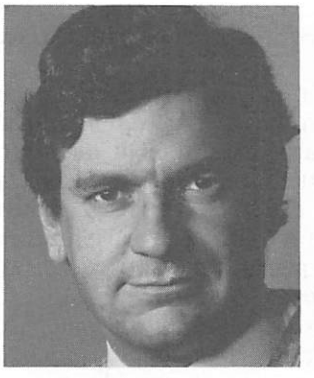
# The development and field trials of the 'A' blade coulter for introducing seed into the soil

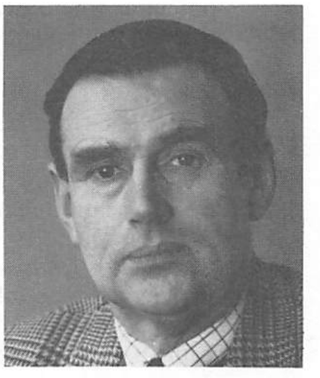
D MacIntyre, A G Gray, M J Sharp

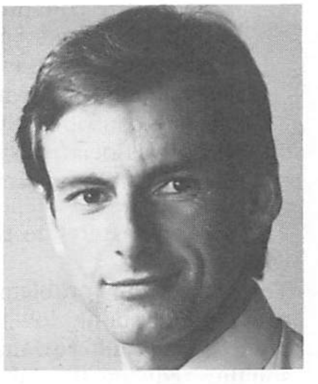
**Summary**

THE performance of commercial coulters for direct drilling was assessed; this indicated the need for improvement in coulter design for direct drills. An 'A' blade coulter was designed and made, the final design emerging after a series of field trials and subsequent modifications.

Trials with the new coulter took place over 5 years (1980–84) and involved comparisons with 3 commercial direct-drills and another prototype drill. The results, for all the machines, indicated that there was little difference in plant establishment whether surface stubble was cultivated or not, or when forward speed was increased. The 'A' blade drill appeared to give its best performance when drilling through surface trash but showed no constant advantage in terms of crop establishment and yield.







*Above: Malcolm Sharp*

*Above right: Duncan MacIntyre*

*Right: Alistair Gray*

## 1 Introduction

Successful commercial coulters in common use for tilled soil include Suffolk, spring tine, chisel, single and multiple disc; however, the operation of these coulters for direct drilling either in unchanged or modified form has not met with the same success (Baker 1976) and has resulted in the need for new designs to be explored (J.C.O. 1979). Work was begun on this problem by staff at the Scottish Institute of Agricultural Engineering (Anon 1976) and at Newcastle University (O'Callaghan 1977) in North Britain.

Although direct drilling has had limited appeal in Scotland with only 0.5% of crops and grass being so sown, and these mainly forage brassicas, it has had a greater impact in England and Wales where 2.7% of crops and grass, mainly cereals, are drilled by this method (Holmes and Gray 1979). The technique has become less popular in recent years (Ozanne 1984) but, nevertheless, it remains an established practice.

Coulters for direct drilling require a greater force for soil penetration than those on conventional drills. The response by manufacturers to this problem was to increase the weight transmitted to the coulter, by increasing the overall weight of the drill and by devising methods to transfer weight from the drill land wheels to the coulters. Although soil penetration problems were largely overcome by these methods, others became manifest in coulter performance. A prerequisite was a dry and friable surface which had clean stubble obtained by either burning or baling. If not, the seed could be inadequately covered so that it was liable to desiccation and/or predation; moreover, surface trash was often dragged down into the soil with subsequent phytotoxic effects on germination (Lynch 1977, Lynch and Gunn 1976). Coulter blockages in trash could be an additional problem.

Initial work at the Scottish Institute of Agricultural Engineering concerned evaluation of the performance of commercial direct drills currently on the market (Gray and MacIntyre 1983), together with an evaluation of the parameters that effect the depth of soil penetration by disc coulters, the most common type fitted to direct drills. Subsequently, design studies were carried out on a coulter that would overcome the shortcomings of commercial coulters listed previously. This resulted in the construction of 'A' blade coulters which were fitted to prototype drills whose performance was compared with various other drills.

---

*Duncan MacIntyre, Alistair Gray and Malcolm Sharp all work at the Scottish Institute of Agricultural Engineering, Penicuik.*

*Refereed paper: manuscript received 12 January 1986 and accepted for publication in revised form 4 April 1986.*

## 2 Design parameters for the 'A' blade coulter

### 2.1 Performance aspects of commercial coulters

The relevant aspects of performance of current commercial coulters for direct drilling are detailed below.

(i) Suffolk coulters lack penetration and are only suited for work on cultivated soil.

(ii) Spring tine coulters cut a channel through the soil but have difficulty penetrating heavier uncultivated soils resulting in variable seed depth and seed coverings. Where there is straw and trash on the surface, it is collected by the coulter spring legs, and this tends to lift the coulters out of work.

(iii) Chisel coulters have reasonable soil penetration potential when attached to a heavy carriage but they do not cover seed well or cope with surface trash.

(iv) Disc coulters have a reasonable capability to cut through surface trash and to penetrate hard soil conditions when sharp and of small diameter. Hence they are fitted as coulters to many commercial direct drills. Nevertheless, their performance is not entirely satisfactory because:— (a) soil penetration and slit depth varies due to an inherent tendency for the disc to lift over hard patches, which results in some seed being poorly covered; (b) in light soils the required depth of sowing is not alway obtained because of premature collapse of the slit sides; (c) in heavy soils the slit sides can be compacted and smeared, resulting in poor establishment of the germinating seedlings; (d) sowing seed below the point of tine entry contributes towards varying seed covering with associated loss of soil moisture round the seed, and predation.

### 2.2 Design features to remedy shortcomings of current coulters

To overcome the problems of performance stated above, seed coulters should sow to one or both sides of the entry point of the coulter so that grain lies below undisturbed soil thus reducing the risks of moisture loss and predation by birds and slugs. Such methods also avoid dragging straw into close contact with the seed. By sowing a row of seeds on each side of the coulter, it is possible to halve the number of coulters on a drill for a given width and thus increase the clearance between individual coulters to reduce the risk of blockage in trashy surface conditions.

## 3 Coulter and drill development

### 3.1 First stage of development

To meet the requirements discussed above, a coulter was constructed consisting of a central leg, with L blades forming wings attached to the bottom (fig 1). These wings worked in a horizontal plane below the soil surface, the seed being deposited below the trailing edge at the outer extremity of each wing by means of a small diameter (15 mm) feed pipe through which seed was conveyed pneumatically. The feed pipe from each wing was turned through 90° below the wing, at the rear of the coulter leg and a flexible pipe from the pneumatic seed conveying mechanism was attached to each of them. Thus, two rows of seed were sown by each coulter unit. To assist coulter penetration into the soil, a flat steel disc was mounted on the front of the coulter sub-frame to make an initial cut. The wings of the share were inclined downwards by 11° to improve penetration and a steel land wheel was fitted at the rear of the sub-frame to provide a means of depth

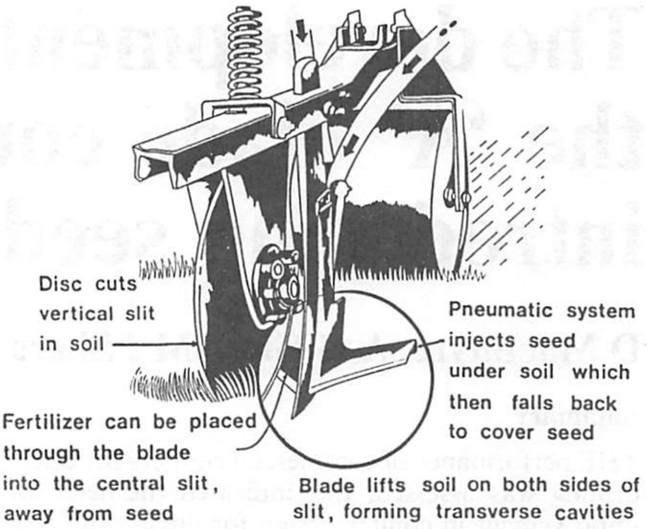



*Fig 1 Principle of 'A' blade coulter*

control. This was required because, after the initial soil penetration had been made by the A blade, the pitch of the coulter wings drew the coulter progressively deeper unless restrained by a roller or a wheel on the surface. One such unit was initially mounted on a semi-mounted toolbar frame and a small fan was used to power the pneumatic conveying system. Results of sowing trials were encouraging, but problems of soil penetration and trash wrapping on the leading edge of the wings occurred because they projected at 90° to the direction of travel. To overcome these problems the wings were repositioned in a "swept back" configuration being angled at 130° to the direction of travel.

### 3.2 Second stage of development

A second-hand International S6–1 drill was modified to dispense seed to four 'A' blade coulter units mounted below it. Each consisted of a soil opening disc at the front, followed by an 'A' blade and then by a depth control roller (fig 2). Airflow for seed delivery was provided by an Accord fan unit driven by an hydraulic motor. The seed delivery was split eight ways in a conical divider to match the requirements of the four coulter units.

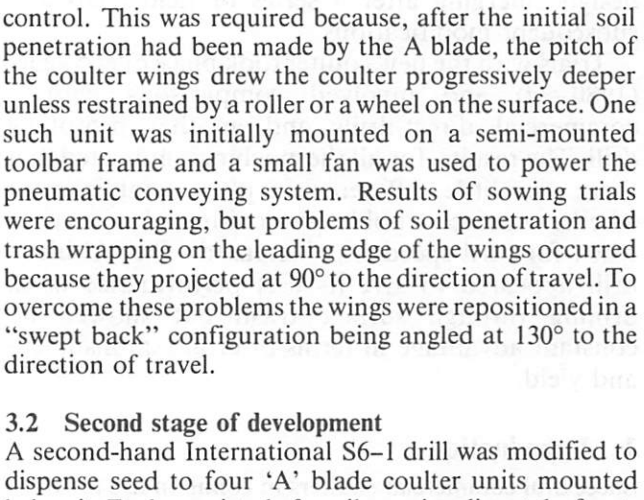


*Fig 2 Mark I 'A' blade coulter*

Field trials indicated a need for the following modifications:

(1) to obtain the best possible clearance and soil flow between coulters, adjacent units should be staggered as in conventional drills;

(2) the wings of the 'A' blade required a greater swept back angle of 142° to the direction of travel, to ensure no roots or trash wrapped round the leading edge;

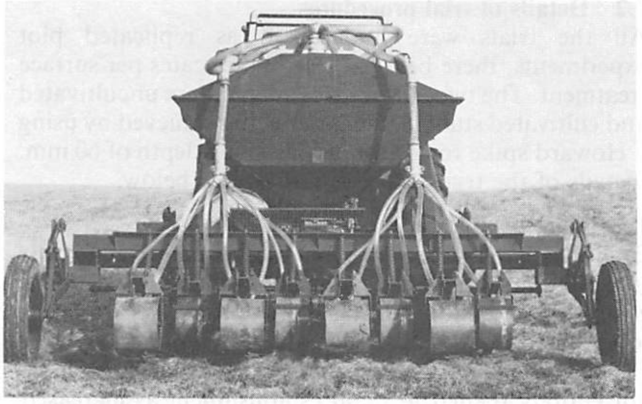


*Fig 3 First prototype 'A' blade drill*

(3) the distance between the 'A' blade and the depth control roller should be increased to prevent the roller running on soil that was still moving after passage over the coulter, to avoid soil build-up on the roller;

(4) an improvement of seed entrainment into the air stream was required.

**3.3 First prototype drill**

A full scale drill was constructed (fig 3) with eight coulter units (16 rows) positioned 330 mm apart, ie seed rows at 165 mm spacing (MacIntyre 1981a). An Accord seed metering and conveying system was mounted on the drill and each coulter unit was modified and fitted to meet the modifications suggested under paragraph 3.2. Each unit was mounted on the drill so that it operated at the end of a trailing arm, ie it was sleeved at the front so that it pivoted on a 38 mm diameter round steel bar fixed across the front of the drill. Pressure for initial soil penetration was provided by vertical compression springs between the top of the coulter unit and the main frame of the drill. Individual spring pressures could be adjusted. The approximate depth of sowing was obtained with a set of adjustable depth wheels on the main frame. Individual coulter depth was obtained by adjusting the position of its rear roller. It was only possible to undertake very brief field testing (see Section 4) before the drill was successively evaluated in further field trials by two commercial companies. Both companies were keen that the potential of the A blade to drill through trash was exploited to the full, so that a future production version would be suitable for a European market in which some direct drilling takes place through chopped maize stover (MacIntyre 1981b). Therefore, another drill was constructed to meet these additional requirements.

**3.4 Second prototype drill**

On the second prototype drill (fig 4), the final modifications to the coulter sub-assembly to obtain completely uninterrupted trash flow under severe conditions were as follows.

(1) The plain leading disc was replaced with a ripple disc to improve trash cutting (fig 5).

(2) The distance between the leading tip of the 'A' blade leg and the periphery of the front disc was found to be critical and a gap of 45 mm was needed to prevent stone blockage whereas a gap 50 mm resulted in trash blockage.

(3) In order to prevent trash from wrapping round the almost vertical 'A' blade leg, spring flickers were mounted on the leading disc (fig 5). A number of designs of spring flickers were tried, the final choice consisting of spring steel strip, 15 x 2 mm in section, mounted in a coil round the disc axle. The inner end of the coil was located in a block on the axle and the outer end was elongated radially with the disc to protrude beyond it so that the 'A' blade leg was wiped as the disc rotated. A second radial tail was riveted to the outer coil of the spring so that it operated at 180° to the tail of the spring itself. The spring flicker system which can also be used for plough skims and disc harrows is covered by patent (MacIntyre 1981c).

*Fig 4 Second prototype 'A' blade drill*

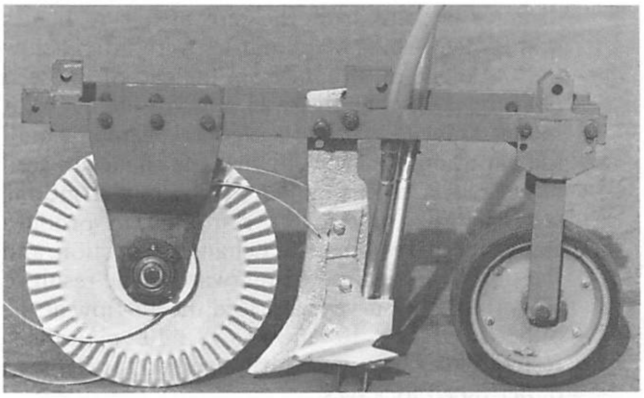


*Fig 5 Mark II 'A' blade coulter with wavy edge disc, spring flickers and rubber tyred depth wheels*

(4) The steel roller at the back of each coulter unit was never entirely satisfactory when working over wet or damp trash. It was replaced initially with a small roller formed from coiled spring steel rod. This was later found to pick up trash at each end of the bearing shafts, and these were changed to a narrow wheel with a loose flat rubber tyre (fig 5) which proved satisfactory.

(5) On the first prototype drill the method of attaching the coulter assembly to the frame of the machine using a front pivot was not satisfactory. Such an arrangement meant that the three components of the coulter, the disc, 'A' blade and depth roller, did not rise or fall by equal distances if an obstruction was encountered. Therefore, in this second prototype, the coulter units were mounted on parallel linkages within the frame and the vertical springs for initial soil penetration were loaded against a transverse beam on the front of this drill. The height of the transverse beam was adjustable, being controlled by hydraulic rams, the operation for coulter height adjustment following the same principle as used on the Massey Ferguson 130 direct drill (Anon 1978).

(6) In addition to modifying the drill to operate in very

trashy conditions, there was also a requirement for the machine to drill successfully in tilled land. Unlike the direct drilled work, passage of the 'A' blade in tilled land left the soil in small ridges and furrows. Although this may be of advantage in heavy land to deflect surface water away from the emerging seedlings, in wet weather it was not aesthetically acceptable so a flexicoil roller was mounted at the rear and at an angle of 120° to the direction of travel of the drill. This left an acceptable finish.

(7) Another problem which had little agronomic significance but which reduced the aesthetic appeal of the work of the drill, was a small variation in row width. In heavy soils, the seed was blown a shorter distance laterally from the ends of the 'A' blades than in light soils. Metal baffles were fitted below the 'A' blade at 19 mm from the end of the seed delivery outlet but this was not satisfactory as it induced blockage in the outlet. To overcome both the variation in row width and the chance of seed outlet blockage, the baffles were removed and the seed delivery pipes were re-routed to produce smoother curves where they changed direction, and the outlets were directed rearwards. The result of smoothing the curves increased the air-flow at the outlet from $7.5 \times 10^{-3}$ m$^3$/s to $18 \times 10^{-3}$ m$^3$/s. This resulted in evenly spaced rows and no further seed outlet pipe blockages.

## 4 Comparison of direct drill performance

The performance of the first prototype machine was compared with one commercial and one other prototype Universal drill from Newcastle University (Sharp and MacIntyre 1980) when sowing winter wheat in 1978 and also with these same drills plus an additional commercial machine when sowing Spring barley in 1979. Similarly, the performance of the second prototype was compared with two commercial direct drills when sowing five trials of Winter barley and two trials of spring barley between 1982 and 1984.

### 4.1 Drills used for comparative purposes

These were as follows.

a) The *Bettinson 3-D drill* has triple disc coulters. A front disc cuts a slit and a following pair of flat discs, angled slightly from the vertical, form a 'V' slit allowing entry of the seed into the ground.

b) The *IH511 drill* has four rows of spring tines each of which having a convoluted seed delivery tube attached to the rear of it. The tine penetrates the ground, forming a small furrow into which the seed is dropped. This particular model of drill is no longer manufactured.

c) The *Newcastle prototype machine* has coulters consisting of a single curved disc set at an angle to the direction of travel. The disc cuts a small furrow, seed is dropped on to the ground and covered with soil from the adjacent furrow.

d) The *Massey-Ferguson 130 drill* has triple disc coulters similar in layout to the 3-D drill, but the leading disc is of small diameter to assist penetration. The coulters are mounted on a parallel linkage.

e) *First prototype 'A' blade drill* (as described previously).

f) *Second prototype 'A' blade drill* (as described previously).

### 4.2 Details of trial procedures

All the trials were undertaken as replicated plot experiments, there being at least 3 replicates per surface treatment. The two surface treatments were uncultivated and cultivated stubble, the latter being achieved by using a Howard spike rotovator at a working depth of 60 mm. Details of the trials are given in table 1 below.

### 4.3 Plant population assessment

Each plot was assessed for plant establishment at growth stage 10, brairding, first leaf through coleoptile (Zadocks *et al* 1974) by counting the individual plants in half a square metre quadrat at 5-10 sampling points.

For both Winter and Spring sown cereals final yield is not entirely related to plant establishment as increased tillering of the brairded crop compensates for lower plant populations (Toosey 1983). However, the type of drill used, by its sowing method, to some extent provides suitable conditions not only for germination and emergence but also for continued plant growth until harvest.

### 4.4 Crop yield assessment

Sites were harvested with a small specially adapted combine harvester. Yields were determined by harvesting a 2.3 m swath, 50-100 m long, from the centre of each plot. Grain moisture content was also recorded.

## 5 Results and discussion

### 5.1 Plant establishment

Plant populations at growth stage 10 (Zadocks *et al* 1974) are given in table 2 in detail; in fig 6 which shows crop populations following the use of different drills and in fig 7 which shows crop populations following the use of different cultivations before drilling or the use of different drilling forward speeds.

At Site 1 the Disc prototype drill produced significantly greater plant emergence ($P \leqslant 0.05$) in all three straw treatments, although in the chopped straw treatment there was no significant difference between it and the 'A' blade drill. The Bettinson 3-D and 'A' blade drills produced very similar results in the burned and baled straw treatments, but in the chopped straw treatment the results from the Bettinson were significantly less ($P \leqslant 0.05$). A possible explanation is that the triple disc type of coulter used on this machine had difficulty in penetrating the straw cover, and tended to deposit the seed in slots in the chopped straw rather than in the ground. Therefore, it is probable then that the seed suffered phytotoxic effects (Ellis *et al* 1977; Barber *et al* 1976; Lynch 1977).

The number of plants/m$^2$ established in the burnt plots was significantly greater than the number in the baled straw ($P \leqslant 0.05$) and the chopped straw ($P \leqslant 0.001$) treatments. Differences between these latter two treatments were not significant.

At Site 2, the IH511 covered seeds and drilled at the correct depth significantly better ($P \leqslant 0.05$) at the two faster forward speeds. This suggested that it was more suited to high speed operation. Conversely, the plant population of the plots of the 'A' blade were significantly lower ($P \leqslant 0.05$) when the machine was operating at the two higher speeds (4.8 km/h and 6.4 km/h). This reduction in plant population was probably due to the 'A' blade coulters going deeper into the ground as the forward speed was increased, which resulted in the seed being sown at too great a depth. Deeper sowing with speed was found to be a characteristic of the 'A' blade drill, whereas the converse was true of drills with conventional coulters. The results of the Disc prototype remained fairly constant whilst the Bettinson 3-D produced significantly good results ($P \leqslant 0.05$) at the slowest and fastest speeds.

Plant establishment was particularly high at Sites 3, 4 and 5; in fact, it is possible the plant populations were greater than desirable (ESCA 1982). At Site 3, plant establishment was significantly better ($P \leqslant 0.05$) from drilling into stubble rather than following a surface cultivation, while the reverse occurred at Site 4. At Site 3, the MF 130 drill provided a greater plant stand ($P \leqslant 0.05$) than the 'A' blade when sowing on surface cultivated land, whereas the 'A' blade provided a greater plant stand

**Table 1 Details of trials**

| *Trial* | *Year of harvest* | *Soil series* | *Soil suitability for direct drilling** | *Surface conditions* | *Crop (variety)* | *Drill makes*** | *Drill speeds, km/h* |
|---|---|---|---|---|---|---|---|
| 1 | 1979 | Easter Bush | 2 | Chopped straw<br>Baled straw<br>Burnt straw | Winter wheat (Mardler) | A,C,E | 4.8 |
| 2 | 1979 | Winton | 3 | Baled straw | Spring barley (Golden promise) | A,B,C,E | 3.2, 4.8<br>6.4 |
| 3 | 1983 | Darvel | 1 | Surface cultivation<br>Stubble | Winter barley (Igri) | A,D,F | 4.8 |
| 4 | 1983 | Macmerry | 2 | Surface cultivation<br>Stubble | Winter barley (Gerbel) | A,D,F | 4.8 |
| 5 | 1983 | Winton | 3 | Surface cultivation | Winter barley (Igri) | D,F | 4.8<br>8.0 |
| 6 | 1983 | Winton | 3 | Surface cultivation<br>Stubble | Spring barley (Golden promise) | A,D,F | 4.8 |
| 7 | 1983 | Carpow | 1 | Surface cultivation<br>Stubble | Spring barley (Golden promise) | A,D,F | 4.8 |
| 8 | 1984 | Darvel | 1 | Surface cultivation<br>Stubble | Winter barley (Igri) | A,D,F | 4.8 |
| 9 | 1984 | Macmerry | 2 | Surface cultivation<br>Stubble | Winter barley (Gerbel) | A,D,F | 4.8 |

* *As evaluated by Research and Advisory Organisations, ie 1 = excellent, 2 = good, 3 = poor (Cannell et al, 1978; Ball, 1984)*
** *See Section 4.1 for key.*

**Table 2 Population of brairded crop (plants/m²)**

| *Site* | *Crop* | *Surface treatment or forward speed* | *Population of brairded crop, plants/m²* | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Drill type* | | | | | | *Standard errors* | |
| | | | *A* | *B* | *C* | *D* | *E* | *F* | *Drill* | *Surface or speed* |
| 1 | Winter barley | Chopped straw | 239+ | – | 287• | – | 271• | – | 5.3 | 7.8 |
| | | Baled straw | 268+ | – | 302• | – | 266+ | – | – | – |
| | | Burnt strawø | 283+ | – | 332• | – | 297+ | – | – | – |
| 2 | Spring barley | 3.2 km/h | 350• | 321+ | 323+ | – | 327 | – | 7.0 | 5.1 |
| | | 4.8 km/h | 319+ | 344• | 323 | – | 295+ | – | – | – |
| | | 6.4 km/h | 341• | 347• | 313+ | – | 297+ | – | – | – |
| 3 | Winter barley | Surface cultivation | 594 | – | – | 632• | – | 551+ | 13.3 | 10.8 |
| | | Stubbleø | 639• | – | – | 651+ | – | 702• | – | – |
| 4 | Winter barley | Surface cultivationø | 615 | – | – | 623 | – | 623 | 8.3 | 5.8 |
| | | Stubble | 612• | – | – | 630• | – | 514+ | – | – |
| 5 | Winter barley | 4.8 km/hø | – | – | – | 643 | – | 640 | 2.8 | 7.2 |
| | | 8.0 km/h | – | – | – | 576 | – | 572 | – | – |
| 6 | Spring barley | Surface cultivation | 234 | – | – | 259 | – | 250 | 7.4 | 6.8 |
| | | Stubble | 230 | – | – | 258 | – | 252 | – | – |
| 7 | Spring barley | Surface cultivation | 272 | – | – | 290 | – | 272 | 26.8 | 26.8 |
| | | Stubble | 242 | – | – | 298 | – | 242 | – | – |
| 8 | Winter barley | Surface cultivation | 458 | – | – | 440• | – | 490+ | 26.6 | 21.6 |
| | | Stubble | 411 | – | – | 393• | – | 444+ | – | – |
| 9 | Winter barley | Surface cultivation | 369 | – | – | 458• | – | 252+ | 16.6 | 11.6 |
| | | Stubble | 361 | – | – | 442• | – | 244+ | – | – |

ø *Significantly greater ($P \leqslant 0.05$) than other surface treatments or forward speeds at the same site.*
x *Significantly greater ($P \leqslant 0.05$) than treatments marked + with the same sub-treatment at the same site.*

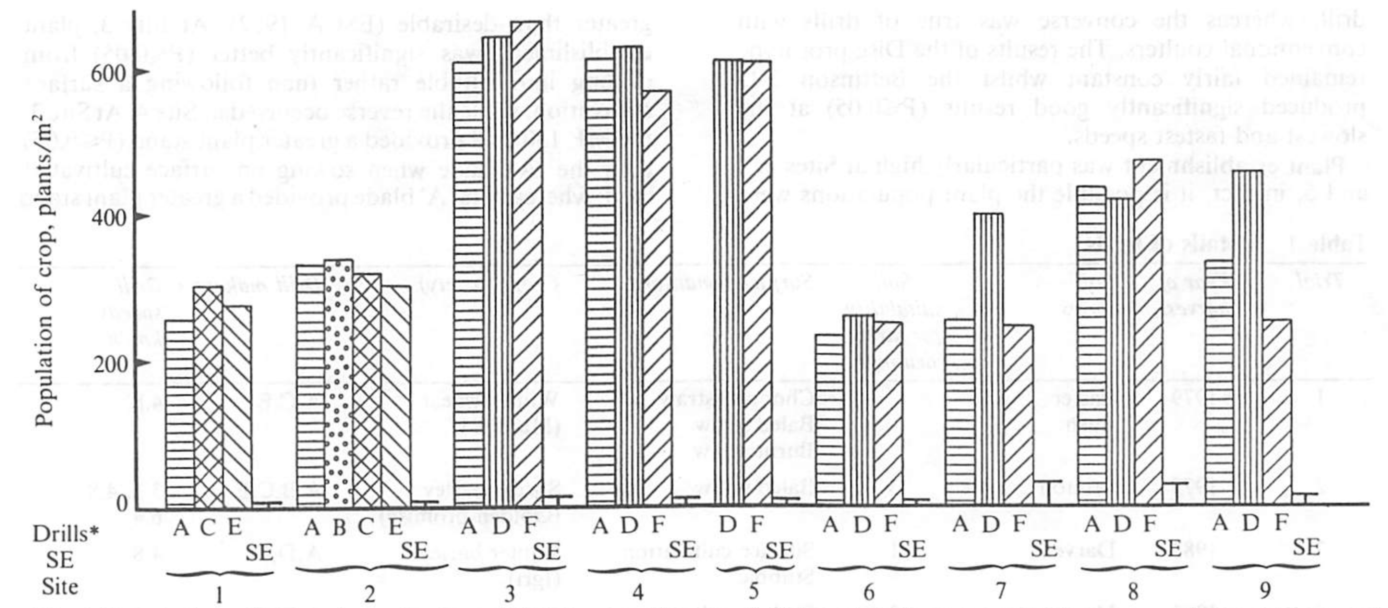



*Fig 6 Population of plants (growth stage 10) following the use of different drills at sowing (*see para 4.1 for drill names)*

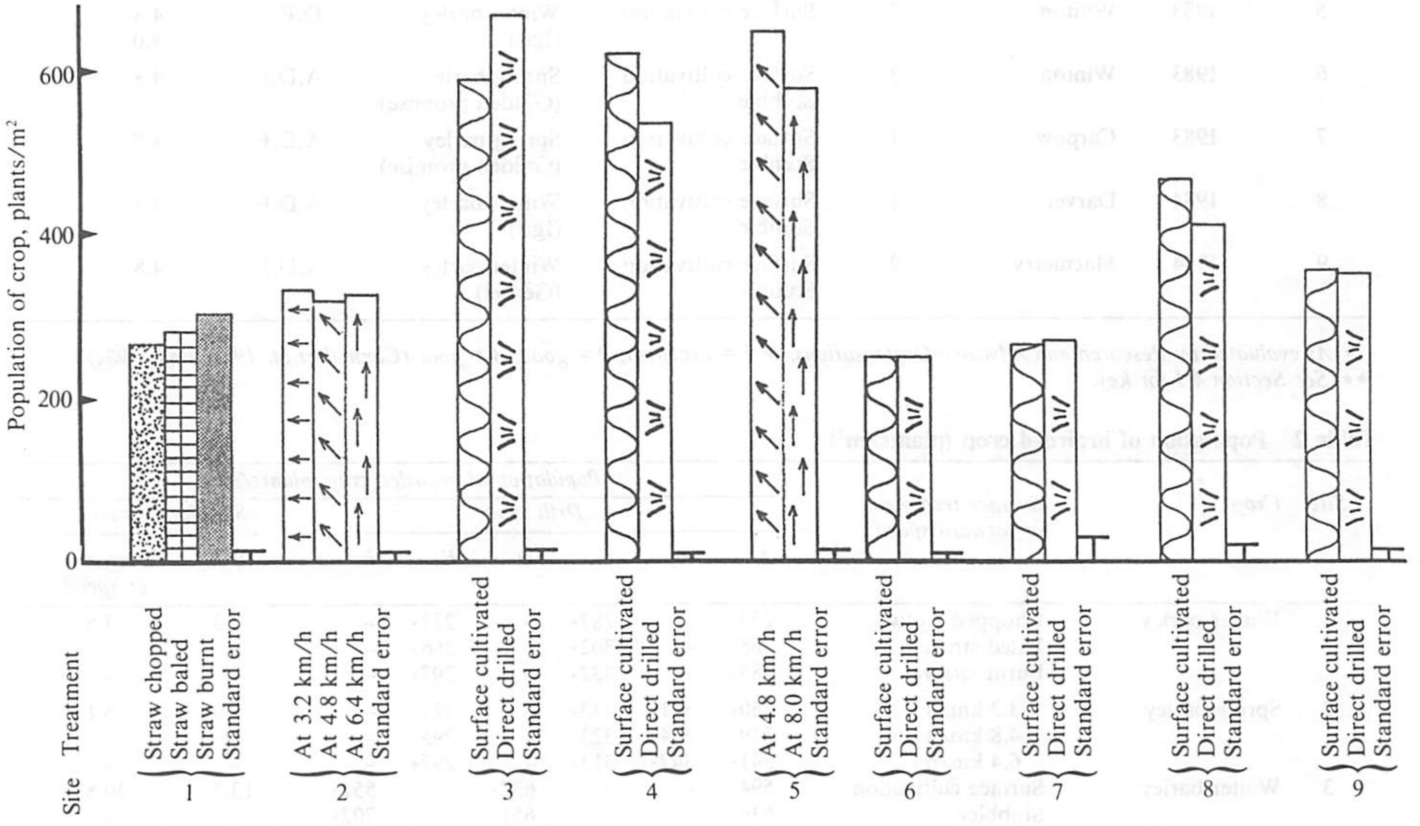



*Fig 7 Population of plants (growth stage 10) following the use of sundry treatments before or at drilling*

($P \leqslant 0.05$) than the other drills on stubble. A better plant stand ($P \leqslant 0.05$) was obtained using the slower of the two forward speeds at Site 5. There was no difference in performance between the two drills used.

The plant populations of the Spring sown treatments at Sites 6 and 7 were rather low, Site 6 had a soil unsuitable for direct drilling, category 3 (Pidgeon and Ragg 1979), whereas Site 7 had a category 1 soil, but both were equally poor in crop stands. The Spring of 1983 was noted for the prolonged wet weather and this no doubt had some effect and might have been responsible for adverse soil physical conditions allowing the land to be more readily compacted by traffic. Root growth after direct drilling can be affected by soil compaction which can cause up to 12% yield reduction (Holmes *et al*, 1981) through low tiller establishment (O'Sullivan *et al*, 1980). At Site 8, the 'A' blade provided a greater plant stand ($P \leqslant 0.05$) than the MF 130 drill when sowing on both stubble and surface cultivated land. The converse of this situation occurred at Site 9. The summer of 1984 was particularly low in rainfall and drought conditions affected the crop at Site 9.

### 5.2 Crop yield

Crop yields are given in detail in table 3 and in fig 8, which shows yields following the use of different drills, and in fig 9, which shows yields following the use of different cultivations before drilling or the use of different forward

**Table 3 Crop yield (tonne/ha)**

| *Site* | *Crop* | *Surface treatment or forward speed* | *Crop yield, t/ha* — *Drill type* *A* | *C* | *D* | *E* | *F* | *Standard error of different drill treatments* |
|---|---|---|---|---|---|---|---|---|
| 1 | Winter wheat | Chopped straw | 5.0 | 4.4 | | 4.4 | | 0.10 |
| | | Baled straw | 6.0 | 6.4 | | 5.8 | | |
| | | Burnt straw | 6.2 | 5.6 | | 5.7 | | |
| 2 | Spring barley | | Not recorded** | | | | | |
| 3 | Winter barley | Surface cultivation | 6.4 | | 6.4 | | 5.8 | 0.16 |
| | | Stubble | 6.5 | | 6.2 | | 6.5 | 0.40 |
| 4 | Winter barley | Surface cultivation | 5.1 | | 4.8 | | 4.8 | 0.30 |
| | | Stubble | 5.5* | | 4.9+ | | 4.8+ | 0.07 |
| 5 | Winter barley | 4.8 km/h | | | 4.9 | | 4.9 | 0.13 |
| | | 8.0 km/h | | | 4.7 | | 4.6 | 0.14 |
| 6 | Spring barley | Surface cultivation | 3.2 | | 3.6 | | 3.5 | 0.41 |
| | | Stubble | 2.9 | | 3.2 | | 2.9 | 0.21 |
| 7 | Spring barley | Surface cultivation | 3.5 | | 3.6 | | 3.3 | 0.12 |
| | | Stubble | 3.3 | | 3.2 | | 3.7 | 0.34 |
| 8 | Winter barley | Surface cultivation | 10.7 | | 10.9 | | 9.7 | 0.38 |
| | | Stubble | 10.0 | | 10.2 | | 9.9 | 0.65 |
| 9 | Winter barley | Surface cultivation | 4.7 | | 4.5 | | 5.3 | 0.60 |
| | | Stubble | 5.2* | | 3.8+ | | 3.6+ | 0.30 |

** Significantly greater (P≤0.05) than treatments marked + at the same site.* *** Due to severe infestation of Agropyren repens.*

speeds. At Site 1, on the chopped straw treatment, plots sown by the Disc prototype drills had a significantly lower crop yield than the Bettinson 3-D and the 'A' blade (P≤0.05). There was no significant difference between the Bettinson 3-D and the 'A' blade. At the same site, on the baled straw treatment, plots sown by the 'A' blade had a significantly lower crop yield than those sown by the Disc prototype (P≤0.05). There was no significant difference

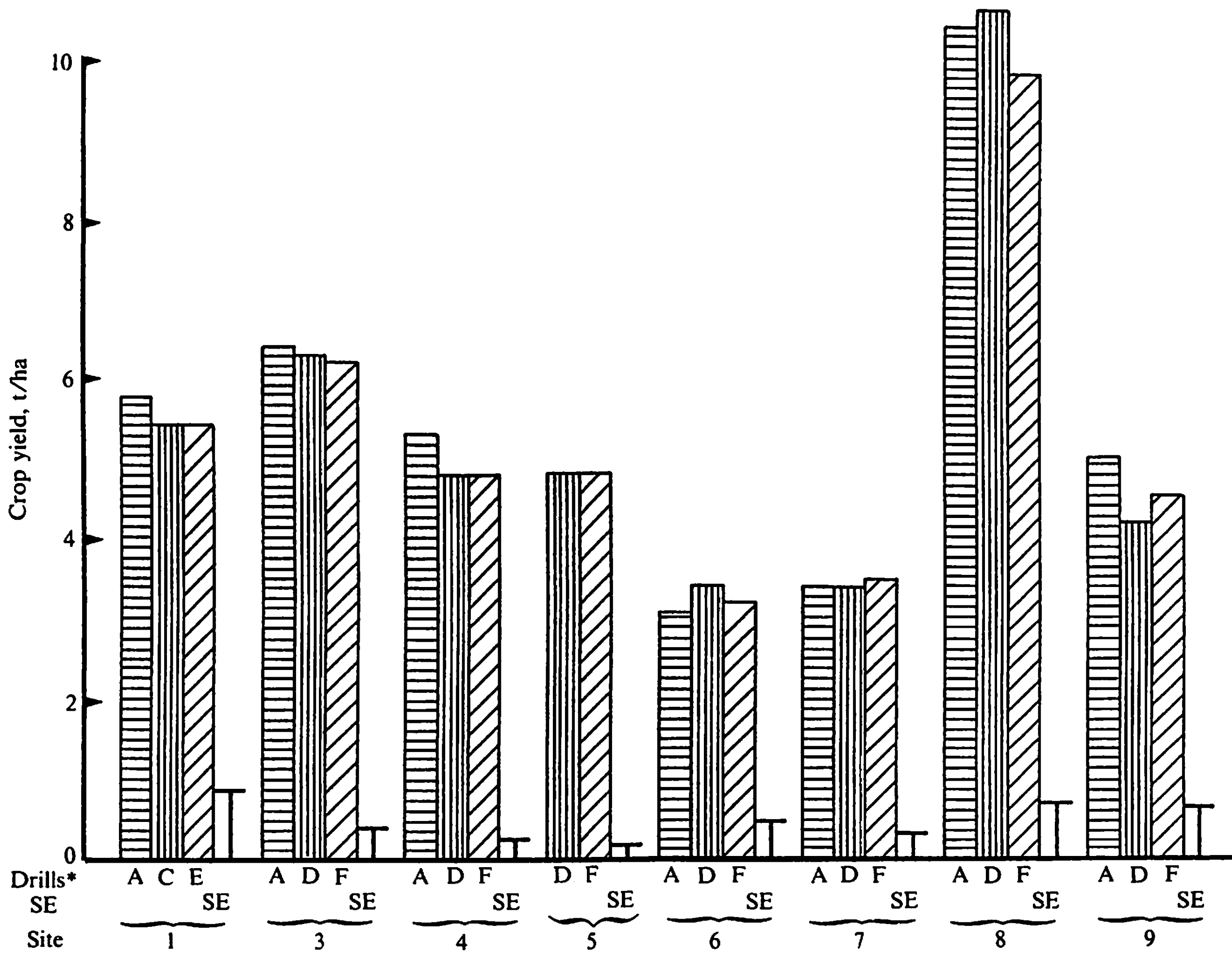



*Fig 8 Crop yields following the use of different drills for sowing (*see para 4.1 for drill names)*

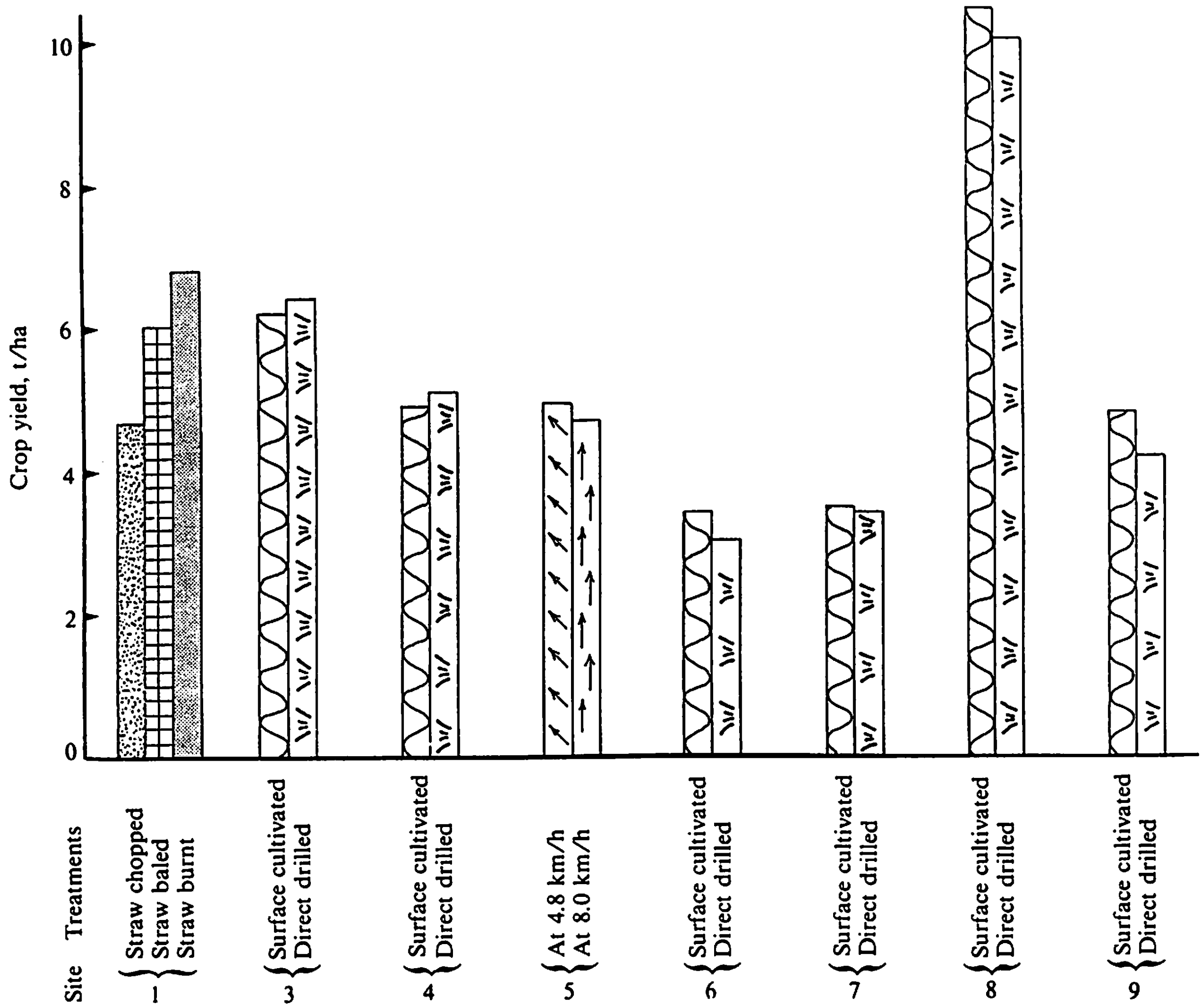



*Fig 9 Crop yields following sundry treatments before or at drilling*

between the Bettinson 3-D and 'A' blade, and the Bettinson 3-D and Disc prototype machines. On the burned straw treatment, both the 'A' blade and Disc prototype plots had a significantly lower crop yield than the Bettinson 3-D plots ($P \leq 0.05$). There was no significant difference between the plots sown by the 'A' blade and Disc prototype machines.

An analysis between the three straw treatments on Site 1 showed that the chopped straw block had a significantly lower crop yield than the baled and burned straw treatments ($P \leq 0.001$). There was no significant difference in crop yield between the baled and burned straw treatments.

The grain yields at three of the five winter barley sites were slightly lower than would be expected. The overall mean yield of each site in 1982-3 reflected the soil suitability for direct drilling, viz: Site 3 (category 1 soil) = 6.3 t/ha, Site 4 (category 2 soil) = 5.3 t/ha and Site 5 (category 3 soil) = 4.9 t/ha. At this last site, lower yields were recorded from the high speed drilling treatments. Of the two winter barley sites sown in 1983-4 (Sites 8 and 9), the overall mean yield of each site again probably reflects the soil suitability for direct drilling, viz: Site 8 (category 1 soil) = 10.4 t/ha and Site 9 (category 2 soil) = 4.8 t/ha, although the latter site was particularly affected by the 1984 summer drought conditions.

Grain yields at both spring barley sites (Sites 6 and 7) were particularly low. Not only was the soil unsuitable at Site 6 (category 3 soil) for direct drilling, but the crop became infested with couch grass. No explanation other than that given under 'Plant establishment' can be offered for the low yield at Site 7, which had a category 1 soil.

There was no significant difference ($P \leq 0.05$) between any of the drills on the surface cultivated treatments. However, on stubble, the crops drilled by the Bettinson 3-D yielded significantly more ($P \leq 0.05$) than the other drills at Sites 4 and 9.

At Site 5 (Winter barley), the higher forward speeds resulted in a reduction of yield from both drills (although these differences were not significant). This was probably due to lack of adequate depth control and seed covering at the higher forward speeds resulting in poorer plant establishment (as shown in table 2), which was not entirely compensated by increased tillering (Toosey 1983).

In general, there was little difference in crop yield whether drilling was undertaken into the stubble or after a light surface cultivation.

## 6 Conclusions

6.1 Although this paper covers nine different trials, these results represent only a small sample of the conditions under which a drill may be required to work. Moreover, there is not a direct relationship between initial crop plant population and final yield. Low populations can be compensated for yield by increased tillering of individual plants (Toosey 1983). This is well illustrated at Site 9 where a significantly low plant population followed drilling with the A blade on surface cultivated plots; but at harvest, this particular treatment returned the highest yield.

6.2 Bearing in mind these provisos, the following conclusions can be drawn from the results of the field trials.

a) Major differences in plant establishment, ie crop yield, occurred between sites, which far surpassed those between different drills, drill forward speeds, or light surface cultivation.
b) The 'A' blade drill showed no general advantage in performance over the two commercial direct drills on stubble from which the straw had been baled. A light surface cultivation on such stubble had little effect on the performance of any direct drill.
c) If, throughout the trials, the later design of 'A' blade drill - with its greater ability to sow through trash and with its improved coulter depth control - had been used, better crop establishment would have been obtained (Choudary *et al* 1985). In areas of the world where surface trash is present and seed is drilled below it (MacIntyre, 1981c), then use of the second prototype with the enhanced performance previously mentioned may be of benefit. However, it is unlikely to be used at present in the UK to drill through chopped straw as farmers prefer to bury or incorporate straw into the soil as an alternative to burning. This method avoids poor seed germination through toxic effects of incomplete straw breakdown (Christian, 1982; Lynch and Harper 1982) and avoids poor coulter performance due to the interference of trash.

It would appear that the 'A' blade has a potential performance to overcome both these factors by drilling without coulter blockage into straw free soil below the straw layer. Nevertheless, the emerging seedling must have the capability to grow through a layer of chopped straw. Further work is required to investigate this aspect of the potential performance of the 'A' blade drill if straw burning restrictions are imposed.

6.3 Drilling at the higher forward speeds recorded in this paper, was not detrimental to plant establishment or yield.

## Acknowledgement

The help and assistance of farmers who provided trial sites, is gratefully acknowledged.

## References

Anon (1976). Soil openers, Cultivations. Biennial Report, Scot Inst agric Engng, Penicuik, 1974-6 pp 16-17.

Anon (1978) MF 130 direct drill. Massey-Ferguson Ltd, Coventry.

**Baker C J** (1976). Experiments relating to techniques for direct drilling of seeds into untilled dead turf. *J agric Engng Res*, **21**, 133-144.

**Ball B C** (1984). Winter barley cultivation requirements. COSAC/SIAE/MISR advisory bulletin, Scot Inst agric Engng, Penicuik.

**Barber D A, Martin J K** (1976). The release of organic substances by cereal roots in soil. *New Phytologist*, **76**, 69-80.

**Cannell R Q, Davies D B, Mackney D, Pidgeon J D** (1978). The suitability of soils for sequential direct drilling of combine-harvested crops in Britain: a provisional classification. *Outlook on agriculture*, **9** (6), 306-316.

**Choudary M A, Guo Pei Yu, Baker C J** (1985). Seed placement effects on seedling establishment in direct-drilled fields. *Soil and Tillage Research*, **6**, 79-93.

**Christian D G** (1982). Straw residues - their effects on soil and Crop - Part 1. Proc 'Burn or Bury' SAWMA Conference, St Ives, Cambs.

**Ellis F B, Lynch J M** (1977). Why burn straw? *ARC Research Review*, **3** (2), 29-33.

ESCA (1982) Cereals and oil seed rape. Seed rates and plant populations. Adv Leaflet 127. East Scotl Coll Agric, Edinburgh.

**Gray A G, MacIntyre D** (1983). Studies of soil penetration by disc coulters of direct drills. *Agric Engr*, **38** (4), 106-110.

**Holmes J C, Gray A** (1979). Potential for direct drilling in Scotland. Technical Note No. 31, Scot agric Colleges and Scot Inst agric Engng, Open Days on direct drilling in Scotland, Penicuik.

**Holmes J C, Lang R W, Lockhart D A S** (1981). Long term effect of ploughing, chisel ploughing and direct drilling on barley. Crop Res Note, May. East Scot Coll Agric, Edinburgh.

Joint Consultative Organisation for Research and Development in Agriculture and Food (1979). Arable crops and forage interboard working party on cultivations. A preliminary report to the board. Min Agric Fish Food, London, p 6.

**Lynch J M** (1977). Phytotoxicity of acetic acid produced in the anaerobic decomposition of wheat straw. *J Appl Bacteriology*, **42**, 81-87.

**Lynch J M, Gunn K B** (1976) Chemical aspects of the production and movement of acetic acid in the soil. Letcombe Laboratory Ann Rept, pp 56-58.

**Lynch J M, Harper S H T** (1982). Straw residues - their effects on the soil and crop - Part 2. Proc 'Burn or Bury' SAWMA Conference, St Ives, Cambs.

**MacIntyre D** (1981a). Agricultural Implement. British Patent No 1603106, Patent Office, London.

**MacIntyre D** (1981b). Report on a visit to Paris, Provins and Fontainbleau, France. Report on Visit. Scot Inst agric Engng, Penicuik.

**McIntyre D** (1981c). Improvements in and relating to soil working assemblies. Detrasher unit. British Patent No. 8112900, Patent Office, London.

**O'Callaghan J R** (1977). Private communication.

**O'Sullivan M F, Ball B C, Hunter R** (1980). Soil and crop conditions in the reduced cultivation experiment for spring barley at Carberry Mains, 1979. Dep Note SIN/298, Scot Inst agric Engng, Penicuik.

**Ozanne J** (1984). High tech's big impact on farming industry. Spring Agriculture Review, the Scotsman Publications, Edinburgh, March.

**Pidgeon J D, Ragg J M** (1979). Soil, climate and management options for direct dialling in Scotland. *Outlook on Agriculture*, **19** (1), 49-55.

**Sharp M J, MacIntyre D** (1980). A comparison of direct drill performance. SIN/295, Scot Inst agric Engng, Penicuik.

**Toosey R D** Arable crops in Primrose McConnell's Agricultural Notebook, (Ed Halley J R) 17th Edn, Butterworth, London, p 130.

**Zadoks G C, Chang T T, Konzak C F** (1974). Decimal code for growth stages in Cereals. *Weed Res*, **XIV**, 415-421.

# Heat pumps for near-ambient grain drying: a performance and economics feasibility study

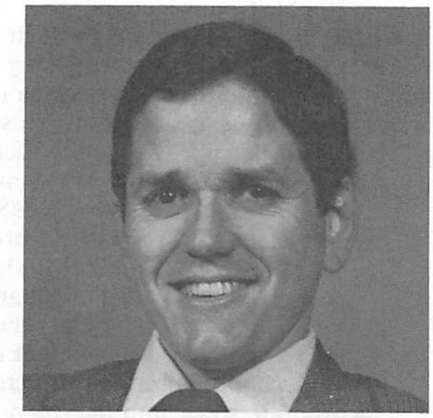

## R C Brook



### Summary

THE heat pump used in near-ambient drying systems is evaluated for its impact on drying cost and overall performance of the drying system. The heat pump is compared against systems using electrical resistance heaters and fan only, no heat, systems. The economics of using the heat pump as an alternative heat source for drying grain are discussed.

Results indicate that the heat pump can reduce energy costs. However, more overdrying will occur, and the risk of grain damage due to mould growth will be greater. The economic analysis indicates that the magnitude of the cost savings is low and cannot justify the capital cost of the heat pump.

## 1 Introduction

Increasing energy costs and constant or decreasing grain prices have prompted grain producers to evaluate their cost of production, including the cost of energy used for drying. Grain harvested in Britain is often dried in bulk grain driers, either 'on the floor' or in bins, using forced ventilation with near-ambient temperature air. During wet or humid weather, an electrical resistance heater may be used to raise the temperature of the air by 3–5>C. The added heat reduces the relative humidity of the air, thus decreasing the drying time required.

Heat pumps have been suggested by researchers as an alternative heat source. A heat pump would increase the temperature of the drying air and under some conditions, would dehumidify the drying air. Bakker-Arkema (1984) reviewed some of the published literature on the use of heat pumps in grain drying. The reduction in energy use varied from 10% for deep-bed drying of wheat (Kutzbach 1978) to 60% for drying corn (Hogan *et al* 1979). In the latter case, the heat pump was used to extract some of the latent heat from the air exhausted from the bulk drying process. Bak (1981a) reported the development of a heat pump for use in the near-ambient drying of barley, and concluded that the heat pump offered an energy saving of 80%.

The following report summarises a study of the operation and performance of a heat pump system for use in the near-ambient drying of wheat in England. First, the performance of the heat pump system as a separate unit is investigated for a range of ambient conditions. The heat pump system is operated according to the control scheme proposed by Bak (1981a,b). The control of the by-pass airflow damper is discussed relative to its impact on successful operation. Next, a model of the performance of the heat pump system is incorporated into a computer simulation of near-ambient temperature drying. The heat pump system is compared with other means of augmenting the drying process using weather data from several areas of the country. An analysis of the economics of utilizing the heat pump system as an alternative heat source for drying grain is also presented.


*Dr Roger Brook is an Associate Professor of Agricultural Engineering at Michigan State University, currently on sabbatical leave with the Crop Drying and Ventilation group at the National Institute of Agricultural Engineering, Silsoe, Bedford.*


## 2 How the heat pump system operates

The heat pump system as proposed by Bak incorporates a by-pass damper as a means of proportioning the amount of the drying air which passes over the coils of the heat pump (see fig 1). During operation, the by-pass damper is adjusted so that a proportion of the total drying airflow passes over the heat pump coils. The remainder of the air passes over the by-pass damper and directly through the fan. The operation of the heat pump system is illustrated in the psychrometric chart in fig 2. During normal operation, the air which passes through the evaporator coil is cooled to temperature $T_1$. If the air temperature is reduced below the dew point during this cooling process some water from the incoming air is condensed. The energy removed in the evaporator coil is then added to the drier, cooler air passing through the condenser coil, thus incorporating a means to upgrade latent heat to sensible heat useful for drying. The air leaving the condenser at temperature $T_2$ is then mixed with the proportion of the drying air by-passing the heat pump, resulting in a flow of drying air which has been dehumidified and heated by 2–4>C.

### 2.1 The by-pass damper

The key to successful operation of the heat pump system lies in the by-pass airflow damper. The intent of the control scheme is to maximise the amount of water removed from the air passing through the evaporator, subject to a constraint on the relative humidity of the air leaving the condenser being greater than approximately 62%. The positioning of the damper, under normal ambient conditions, is controlled

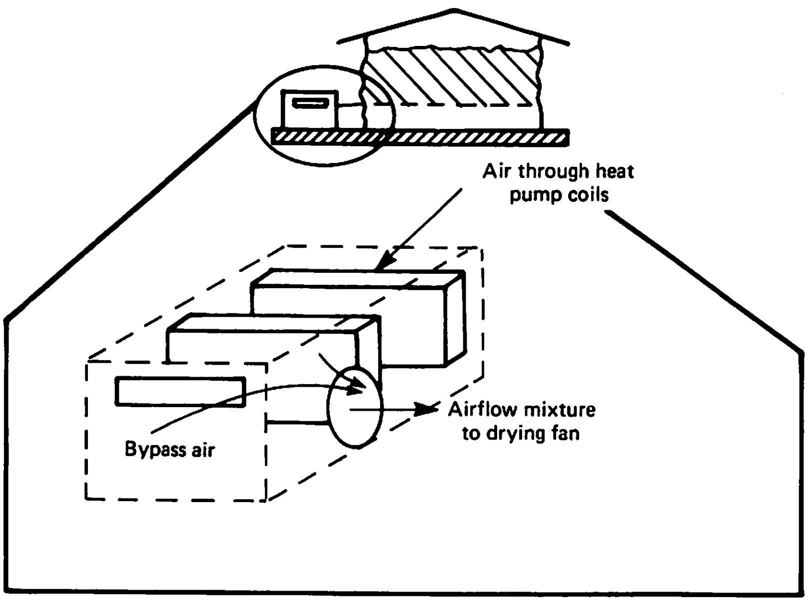



*Fig 1 Schematic of the airflow through a heat pump installed on a grain drying bin*

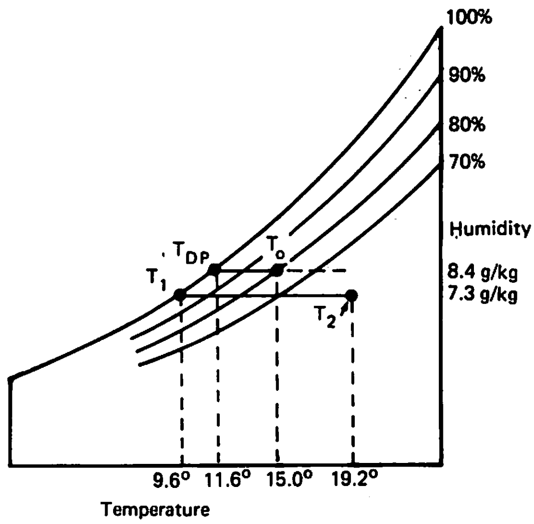



*Figure 2 Heatpump enthalpy transfer represented on a psychrometric chart. Actual conditions for a heatpump with Bak control at ambient conditions of 15°C and 80% RH*

such that the sum of the temperature drop across both coils ($dT_k$) equals 15>C (Bak, 1981a). Referring to figure 2, $dT_k = (T_o - T_1) + (T_2 - T_1)$. The effect of having $dT_k$ = 15>C is that when the relative humidity of the air falls below 62–64%, there will be no condensation of water on the evaporator coils. Then the only temperature rise for the air passing through the heat pump coils comes from the heat generated by the electric motor running the compressor. Therefore, as the ambient relative humidity decreases, the amount of water condensed will decrease. Conversely as the ambient air conditions become cooler and wetter, the proportion of air passing over the heat pump coils will increase, and more water will be condensed.

**2.2 Operation in cold temperatures**
As the ambient temperature decreases, it is possible that the water condensed on the evaporator coils will freeze, causing ice build up. Since this condition should be avoided, the control strategy for the by-pass damper is altered when the temperature of the air passing through the evaporator falls below 6.5°C (Nellist, 1985). Under this condition, the by-pass damper is gradually closed, thus increasing the proportion of the drying airflow passing through the heat pump coils, to attempt to keep the temperature of the air flowing through the evaporator at 6.5°C. The temperature difference sum $dT_k$ will then be less than 15°C. If the air temperature leaving the evaporator falls below 2.5°C, then the heat pump system is shut down.

**2.3 Operation of the heat pump system under various ambient conditions**
The description of the heat pump system given above was used to write a FORTRAN program to determine the operating conditions for specified ambient temperatures and humidities. The program is developed from the viewpoint of air psychrometrics, as presented in figure 2, and the discussion of the airflow by-pass damper control presented in sections 2.1 and 2.2. The estimated performance of a 5.5 kW heat pump system, presented in table 1, compares favourably with the experimental conditions reported by Bak (1981b). At 5°C, the heat pump system operates only during high relative humidity, at 100% airflow over the coils, because of the 2.5°C limitation on the evaporator coil. At 10°C and relative humidities below 100%, the heat pump system is operating at 100% airflow, but also below an evaporator temperature of 6.5°C. Therefore, the summed temperature difference, $dT_k$, is less than 15°C. Note also that, at 60% relative humidity, there is no water removed and hence no latent heat recovery. This occurs at ambient temperatures above 5°, even though $dT_k$ = 15°C.

## 3 Analysing the heat pump system with bulk grain driers

The heat pump system is one of several alternatives available for adding heat to the airflow in bulk grain driers. Adding heat during the drying process increases the rate of drying, and may be particularly advantageous during times of high ambient humidity. The heat pump

**Table 1 Estimated performance of a 5.5 kW heat pump system under various ambient conditions**

| | *Relative humidity, %* | | |
|---|---|---|---|
| | *100* | 80 | 60 |
| *Ambient temperature = 5°C* | | | |
| Evap temp., °C | 2.7 | — | — |
| Cond temp., °C | 7.7 | — | — |
| Airflow ratio, % | 100 | — | — |
| Water removed, kg/h | 22.5 | — | — |
| *Ambient temperature = 10°C* | | | |
| Evap temp., °C | 6.5 | 6.2 | 5.7 |
| Cond temp., °C | 15.3 | 11.3 | 10.7 |
| Airflow ratio, % | 58 | 100 | 100 |
| Water removed, kg/h | 25.6 | 5.8 | 0 |
| *Ambient temperature = 15°C* | | | |
| Evap temp., °C | 11.3 | 9.6 | 8.1 |
| Cond temp., °C | 22.6 | 19.2 | 16.1 |
| Airflow ratio, % | 46 | 54 | 64 |
| Water removed, kg/h | 28.2 | 15.3 | 0 |
| *Ambient temperature = 20°C* | | | |
| Evap temp., °C | 16.7 | 14.7 | 13.1 |
| Cond temp., °C | 28.4 | 24.5 | 21.1 |
| Airflow ratio, % | 45 | 54 | 64 |
| Water removed, kg/h | 32.8 | 17.4 | 0 |

system has the additional advantage of reducing the drying air humidity which will also increase the rate of drying. However, it is not clear, from a simple analysis as presented above if the heat pump will contribute in a cost effective manner to the success of a bulk grain drying system under a variety of weather conditions.

The success of a bulk grain drying system depends on drying the grain to a suitable average moisture content, at an acceptable cost for the energy required, while avoiding any mould growth or related heat damage to the grain. In order to investigate the performance of the heat pump in a bulk grain drying system, the simulation routines were incorporated into an existing NIAE simulation model (Sharp 1983) of near-ambient temperature bulk grain drying. Since the NIAE model used historical weather data, the heat pump system could be compared against other heat sources and management strategies at various locations around the country.

For the purpose of comparison, a bulk batch of 100 tonnes of wheat was dried from 20% wb until the average moisture was reduced to at least 15% wb and the top layer was reduced to 16% wb. The grain depth was 3 m, using an airflow of 18,000 $m^3/h$ (0.12 m/s). The analyses assumed that the drying floor did not add excessive resistance to the flow of the drying air. The hourly weather data used was for the years 1951–70 for Heathrow Airport, London. The starting date for drying was August 15th. The heat pump was sized at 4 kW with a design airflow of 16,000 $m^3/h$ and an enthalpy flux of 85 MJ/h.

### 3.1 The heat pump system versus electrical resistance heaters

A common means of adding heat during the drying process is to use an electrical resistance heater. The performance of the heat pump in a bulk drying system was compared with three systems using electrical resistance heaters. For a temperature rise of 5°C, a 30 kW heater is recommended (ADAS, 1982). Alternatively, a heater of 4 kW was used for the same nominal power consumption as a system using a heat pump. The heaters were controlled such that when the ambient relative humidity was greater than 70%, the heaters were turned on. Recall that the previous discussion (section 2.1) indicated that the heat pump reduced the air humidity when the relative humidity was greater than 62–64%.

The third system in the comparison used an electrical resistance heater of 30 kW operated in three stages. If the drying air was greater than 70% relative humidity, then the first stage (1/3 of the heater) was turned on. If the drying air was still greater than 70%, then the second stage was turned on. Likewise with the third stage. The staging of the 30 kW heater reduced the large decrease in relative humidity observed when the full 30 kW was turned on, thus more closely emulating the performance of the heat pump.

### 3.2 The heat pump system versus no-heat drying

The use of heat to augment the drying process may, in fact, not be desirable. The added heat will certainly decrease the drying time required, and will even out the variation in performance between different years. However, as discussed earlier, one measure of success of a bulk grain drying system is its impact on grain quality, and specifically on the risk of damage due to mould growth. The addition of heat will raise the temperature of the grain, thus increasing the risk of mould growth in the top layers, or the wettest layers, during the drying period.

Previous research on drying corn in the US (Colliver et al, 1983; Van Ee and Kline, 1979) has indicated that "fan only" systems were not only more efficient with respect to energy consumption, but also completed drying with less risk of spoilage. The performance of the heat pump in a bulk drying system was compared with two systems using no added heat. In the first case, the drying system was operated with the same size fan as used with the heat pump system (normal fan). The second case increased the fan size to add approximately 4 kW of nominal power consumption (airflow of 21,600 $m^3/h$), and will be referred to as the larger fan system.

### 3.3 The heat pump system for other locations in England

The weather conditions observed during drying have a significant impact on the success of any drying system. Because of the way in which the heat pump system reacts to reduce the humidity of the drying air, it could be argued that it would be better used in areas of high ambient humidity. The bulk grain drying analyses described above were repeated using weather data from two other locations, Plymouth and Elmdon, near Birmingham. The performance of the heat pump system is compared to a larger fan system.

## 4 Discussion of results

The results for a heat pump system compared to three electrical resistance heater systems and two no-heat systems drying wheat using Heathrow weather data are presented in table 2. The results for a heat pump system compared to a larger fan, no-heat system for Heathrow, Plymouth and Elmdon are presented in table 3. The basis of comparison of the heat pump system against other systems must be four fold: firstly, the moisture content of the grain after the completion of drying and the drying time required; secondly, the energy consumption of the different drying systems which can be measured by the specific energy (MJ/kg) required to remove one unit of water. A better measure is the operational energy (MJ/tonne of dried grain) which directly relates to the energy cost for drying per tonne of grain available for sale after drying is finished. Thirdly, the excess weight loss (kg/tonne of dried grain) represents an opportunity cost, since the weight lost below the target average moisture content is weight that often could have been sold. The last comparative factor is the risk of spoilage due to mould growth. The spoilage index used in tables 2 and 3 represents a relative measure of the likelihood of spoilage occurring in the top layers of the grain during the 20 years analyzed. A lower spoilage index represents less risk.

## 4.1 The heat pump system energy consumption

Bak (1981a) reports an energy saving of 80%, based on the energy required per unit volume of drying air. However, a saving in energy consumption of this magnitude would occur only if both systems required the same amount of time to complete drying. The data in table 2 indicates that the heat pump system requires more time to complete drying than the 30 kW electrical resistance heater system or the larger fan system, but less time than the normal fan system, the 4 kW electrical resistance heater system and the 30 kW staged electrical resistance heater system.

Table 2 **Bulk grain drying analysis for wheat using Heathrow Airport, London weather data for 1951–1970**

| *Heat Source* | *Heat pump, 4 kW* | *Electrical heater, 4 kW* | *Electrical heater, 30 kW* | *Staged heater, 30 kW* | *No heat, normal fan* | *No heat, larger fan* |
|---|---|---|---|---|---|---|
| Initial moisture, % w.b. | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| Final average moisture, % wb | 12.6 | 13.3 | 12.0 | 12.5 | 13.6 | 13.3 |
| | (0.66)* | (0.88) | (0.40) | (0.51) | (1.00) | (1.00) |
| Drying time, h | 288.0 | 330.0 | 263.0 | 284.0 | 355.0 | 275.0 |
| | (23.1) | (36.5) | (13.8) | (17.5) | (50.04) | (34.0) |
| Heat source time, h | 288.0 | 176.0 | 141.0 | 76.0 | — | — |
| | (23.1) | (51.0) | (32.6) | (22.4) | — | — |
| Specific energy, MJ/kg (water) | 1.9 | 2.3 | 2.9 | 2.3 | 2.0 | 2.3 |
| Operational energy, MJ/tonne (grain) | 170.0 | 189.9 | 289.7 | 219.5 | 157.8 | 193.3 |
| Excess weight loss, kg/tonne (grain) | 28.0 | 19.8 | 34.3 | 28.6 | 16.3 | 19.5 |
| Spoilage index** | 4 | 5 | 2 | 2 | 6 | 1 |

**Numbers in parenthesis are standard deviations for the 20 years studied*
***The spoilage index can vary from 0 to 20, with 0 indicating no risk of spoilage*

Table 3 **Bulk grain drying for wheat using weather data for London, Plymouth and Elmdon for 1951–1970**

| *Location* | *Heathrow* | | *Plymouth* | | *Elmdon* | |
|---|---|---|---|---|---|---|
| *Heat source* | *Heat pump, 4 kW* | *No heat, larger fan* | *Heat pump, 4 kW* | *No heat, larger fan* | *Heat pump, 4 kW* | *No heat, larger fan* |
| Initial moisture, %, wb | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 | 20.0 |
| Final moisture, % wb | 12.6 | 13.3 | 13.3 | 14.5 | 12.8 | 13.6 |
| Drying time, h | 288 | 275 | 325 | 352 | 306 | 300 |
| Specific energy, MJ/kg (water) | 1.9 | 2.3 | 2.3 | 3.6 | 2.1 | 2.6 |
| Operational energy, MJ/tonne (grain) | 170.0 | 193.3 | 194.3 | 246.4 | 184.0 | 208.8 |
| Excess weight loss, kg/tonne (grain) | 28.0 | 19.5 | 19.6 | 5.9 | 25.0 | 15.4 |
| Spoilage index* | 4 | 1 | 11 | 5 | 1 | 1 |
| Average ambient conditions | | | | | | |
| — temperature, °C | 16.3 | 16.3 | 15.5 | 15.5 | 14.9 | 14.9 |
| — relative humidity, % | 76.7 | 76.6 | 85.1 | 84.9 | 79.2 | 79.2 |

**The spoilage index can vary from 0 to 20 with 0 indicating no risk of spoilage*

On the basis of the operational energy required to dry the 100 tonne batch, the heat pump system would increase energy consumption by 7.7% compared with the normal fan system. However, the heat pump system would reduce energy consumption by 41.3% compared with the 30 kW electrical resistance heater; 10.5% compared with the 4 kW electrical resistance heater; 22.6% compared with the staged 30 kW electrical resistance heater; and 12.1% compared to the larger fan system.

When comparing the heat pump system with a fan only system at the other locations, note from table 3 that the heat pump system could reduce energy consumption by 21.1% at Plymouth and by 11.9% at Elmdon, as compared to 12.1% at Heathrow. This does indicate that the heat pump system is better suited to more humid climates.

### 4.2 The heat pump system and excess weight loss

One important factor too often neglected when analysing bulk drying systems is the overdrying which occurs. Overdrying, which results in excess weight loss, occurred because of the requirement that the top of the bed should not exceed a moisture content of 16% wet basis. In order to achieve that requirement, the lower layers were usually overdried. The amount of overdrying generally increased at higher drying air temperatures and lower drying air humidities. The heat pump system was prone to overdrying because of the operating characteristics which not only add heat, but also reduce the humidity of the drying air.

The heat pump system resulted in significantly greater overdrying than all systems compared except the two 30 kW electrical resistance systems. The overdrying problem occurred when using the heat pump system in all three locations, as illustrated in table 3. Also note that the overdrying difference between the two systems was much greater for the wetter climate experienced at Plymouth.

### 4.3 The heat pump system and the spoilage index

Bulk drying systems are susceptible to a loss in grain quality due to mould growth, particularly in years of high ambient temperature and/or high ambient relative humidity. The results presented in tables 2 and 3 indicate that the heat pump system could reduce the risk of spoilage compared to a normal fan system or one using a small electrical resistance heater. However, it is important to note that the larger fan system is equal to or better than the heat pump system with respect to the risk of spoilage at all three locations investigated.

## 5 The economics of the heat pump system in bulk drying

Reducing the amount of energy used for drying is desirable from the viewpoint of conservation of a non-renewable resource. However, the operator of a bulk drying system must be concerned with the energy cost for drying. An allowance must also be made, when comparing alternative systems, for the cost of overdrying. Normally, the excess weight lost during overdrying could have been sold at market prices.

The cost calculations presented in table 4 used an electrical energy cost of 5.4 p/kWh and cost for wheat of £100/tonne or 10 p/kg. The electrical energy pricing is based only on units consumed, and assumes that demand charges will be similar for alternative systems. The allowable net investment is calculated by applying the annual savings in operating cost to pay off the investment in five years at an interest rate of 12%. The allowable net investment is the additional investment above the cost of the alternative heat source which can be justified for the purchase of the heat pump. There is no accounting for maintenance costs, which are expected to be higher for a heat pump than for an electrical resistance heater.

The savings in energy cost alone were discussed in section 4.1 above. Considering only the saving in energy cost, an additional investment of £649 could be justified for a 100 tonne batch per year above the cost of a 30 kW electrical resistance heater. However, when compared with a larger fan system only £126 of additional investment could be justified.

More realistically, the cost savings due to energy cost and due to overdrying should be considered. Only when compared with the 30 kW electrical resistance heater system did the heat pump system result in a positive annual net cost saving. In all other cases, the annual operating cost of the heat pump system was greater.

When compared against the single stage 30 kW electrical resistance heater, the annual cost savings for using a heat pump was 31.2% with an allowable net investment of 875 p/tonne of grain dried. Therefore, if only one 100 tonne batch of grain is dried per year, the drier operator could justify up to £875 above the cost of the 30 kW electrical resistance heater on the purchase of a heat pump. However, if that 30 kW heater were operated in 3 stages, an added investment of only £288 could be justified for the purchase of a heat pump.

**Table 4 Average annual costs for bulk drying wheat using Heathrow weather data; electrical energy costs 5.4 p/kWh, wheat sells for 10 p/kg**

| | *Heat pump, 4 kW* | *Electrical resistance heater, 4 kW* | *Electrical resistance heater, 30 kW* | *Staged heater, 30kW* | *No heat, normal fan* | *No heat, larger fan* |
|---|---|---|---|---|---|---|
| Annual energy cost, p/tonne | 255 | 285 | 435 | 329 | 237 | 290 |
| Allowable net investment, p/tonne* | — | 108 | 649 | 267 | — | 126 |
| Annual over-drying cost, p/tonne | 280 | 198 | 343 | 286 | 163 | 195 |
| Cost savings including overdrying, % | — | (10.8) *** | 31.2 | 13.0 | (33.8) | (10.3) |
| Allowable net investment, p/tonne** | — | — | 875 | 288 | — | — |

**A five year payback with an interest rate of 12% and a saving in only energy cost*
***A five year payback with an interest rate of 12% and savings in both energy and overdrying cost*
****Numbers in parenthesis represent a net annual loss*

## 6 Conclusions

- The energy savings of the heat pump against alternative systems varied from 10.5% compared with an electrical resistance heater of the same nominal power consumption to 41.3% compared with a recommended size of 30 kW electrical resistance heater.
- The weight loss due to overdrying with the heat pump was less than the 30 kW electrical resistance heater systems, but greater than occurred with the other systems.
- The heat pump system may give a greater energy saving during wet drying weather, but the overdrying which occurs will be greater.
- The risk of grain spoilage due to mould growth will be greater with the heat pump system than with other normal means of augmenting the drying process.
- The heat pump system may, under some circumstances, reduce the operating cost of a bulk drying system; however, the magnitude of that cost saving will not be great enough to justify the capital cost.
- If the current fan is not sufficient for successful operation of a bulk grain drying system, then the use of a larger fan may be a better alternative than a heat pump or an electrical resistance heat source; however, caution must be exercised so that the fan is not oversized, thus resulting in excessively high specific energy consumption because of the static pressure increase at increasing airflow.

## Acknowledgements

The author wishes to thank Mr F M McKeever who began updating the NIAE near-ambient drying model to incorporate the analysis of heat pump systems, and Michigan State University for granting sabbatical leave during which this work was carried out.

## References

ADAS (1982). Bulk grain driers. Booklet 2416. Min Agric Fish Food.

**Bak C K** (1981a). Dry air generator for flat grain storage. Rpt No 208, Physics Lab I, Tech Univ of Denmark, Lyngby.

**Bak C K** (1981b). Experimental performance of 5.5 kW dry air generator. Rpt No. 209, Physics Lab I, Tech Univ of Denmark, Lyngby.

**Bakker-Arkema F W** (1984). Selected aspects of crop processing and storage: A review. *J agric Engng Res,* **30,** 1–22.

**Colliver D G, Peart R M, Brook R C, Barrett J R** (1983). Energy usage for low temperature grain drying with optimized management. *Trans Am Soc agric Engrs,* **26,** 594–600.

**Hogan M R, Muller R E, Foster G H, Ayers D L** (1979). Development and testing of a heat pump grain dryer. Tech Paper 79-3527. Am Soc agric Engrs.

**Kutzbach H D** (1978). Heat pumps — their potential for drying. *Agrartech*

*Ber*, 4, 55–66.
**Nellist M E** (1985). Personal communications.
**Sharp J R** (1983). The design and management of low temperature grain driers in the UK — A simulation study. Div Note DN 1204, Natl Inst agric Engng, Silsoe, September.
**Van Ee G R, Kline G L** (1979). Management strategies for corn production and low temperature drying. Tech Paper 79-3032. Am Soc agric Engrs.

# Book Reviews

## Management Handbook for Engineers and Technologists

### Barry T Turner and Michael R Williams

*Publisher* Business Books Ltd; imprint of the Hutchinson Publishing Group, 17-21 Conway Street, London W1P 6JD. 1985. ISBN 0 09 147461 2 £10.95 (paperback).

SOONER or later the majority of successful engineers face the transition from engineering to management, and it is characteristic of industry that, whereas great emphasis is placed upon technical qualification, there is frequently little or no opportunity for a senior engineer to undergo formalised training before assuming the new, very different and often greater responsibilities of management,

Management has long been recognised as a subject for systematic study and, whilst there is a plethora of text-books on the subject, there are relatively few which have been written by engineers for engineers. This book addresses the subject very much from the viewpoint of an engineer and if, in defining business objectives, it almost seems to apologise for the over-riding need to make profits, that is a sentiment which might strike a chord in the heart of many an engineer, at least at the start of his managerial career. The authors make the point at an early stage that whilst engineering is primarily concerned with hardware and ideas, management essentially involves people and human relationships.

It is, therefore, entirely logical that the main thrust of the book is directed towards an understanding of the art of tapping the resources of individual human beings and of motivating them to achieve the performance and results that the organisation requires. In the process, however, a useful over-view is provided of the many facets of management, beginning with a scene-setting chapter, and going on through "Knowledge of the business" to look more specifically at "Managing the engineering activity" and "Managing the human aspects". The book concludes with sections on "Types of technical manager" and "Training and education for management".

The Handbook would not claim to be a definitive work on the subject of management for engineers but without question it provides a very useful introduction to the topic. The first stage of any learning process is the development of an awareness of how much one does not know, and after reading it an engineer will certainly look on management and managers through newly-opened eyes.

Probably the most notable omission is any serious reference to industrial relations and the techniques applicable to the establishment of harmonious relationships throughout an organisation. Similarly, industrial disputes are scarcely referred to, and strikes not at all. A manager seeking guidance through the maze of complex industrial legislation and regulation which besets every employer today would search this book in vain for information more specific than the general observation that the extreme difficulty today of terminating employment has contributed to the current high level of unemployment. At a time of crisis, he might find this remark to be as helpful as that of the Irish countryman who, when asked for directions, replied: "If I wanted to get there, I wouldn't start from here".

All in all, however, the Handbook does a great deal of what it says if does. It sets out some of the ways in which engineers can help themselves to become successful managers and gives them an understanding of what management entails. It is also readable and worth reading.

*JVF*

## Elementary Soil and Water Engineering, 3rd Edition

### C O Schwab and R K Frevert

*Published:* John Wiley and Sons Ltd, Baffins Lane, Chichester, West Sussex PO19 1UD, 1985. ISBN 0 471 825875. £26.50 (paperback).

MANY readers will be familiar with Schwab *et al Soil and Water Conservation Engineering* as an important text aimed primarily at design engineers and which has been available in this country for many years. Predominantly, this same authorship produced *Elementary soil and water engineering,* the third edition of which is now available. Unlike its counterpart it has been written primarily for student instruction with the aims of promoting up-to-date information in a form that will be useful for a relative beginning in this discipline. The book certainly succeeds in its purpose including subject matter on the complete range of design principles and layout practices.

Individual chapters cover relationships between water engineering and world food problems, aspects of surveying, elementary hydrology, and soil erosion control. Water supply and storage, field drainage and irrigation, with an emphasis on sprinkler and trickle systems, are also discussed in separate chapters.

The text has many worked examples to explain elementary design procedures and also contains a comprehensive list of references.

It should be pointed out that the book is based primarily on American experience and conditions. Further, it is disappointing that the text is presented exclusively in imperial and US units.

However, the book's great strength is its comprehensive coverage of the discipline. This should make it an attractive choice as a reference work for anyone studying this subject despite its rather high purchase price.

*MJH*

# Electronics on farm machinery: more productivity or more problems?

M R Potter

## Introduction

AT a first impression, agriculture and electronics would seem to be strange bedfellows – agriculture with its mysterious associations with Mother Nature and hoary handed sons of toil, and electronics with equally mysterious associations with another side of Mother Nature and the delicate touch needed to manipulate micronic components.

Despite the apparent incongruousness, agriculture has a great deal to gain from the sensible application of electronics, provided that adequate steps are taken to ensure that the increase in productivity far outweighs any problems that may occur.

Agricultural machinery manufacturers, whether the local blacksmith or a multinational such as Massey-Ferguson, have always kept one eye on the practical needs of the farmer, and the other eye upon the evolving technologies that could be adapted to their needs. In particular, we have drawn heavily, upon evolution in the automotive industry. The commercial availability of a special steel, or a heavy duty bearing or battery, is often determined by the automotive industry volumes justifying the manufacturing investment. However, in the case of electronics, we tend to draw more heavily upon the evolution in the space/aeronautical and communications industries, tempering the availability of appropriate sensors and microprocessors with the

particular needs of the agricultural operating environment.

Before I describe how we in Massey-Ferguson apply electronics, let me define what we mean by electronics.

Firstly, we are concerned with *Monitoring Systems* that will provide information to the vehicle operator or the farm manager. This information will relate to vehicle operating parameters, such as vehicle speed or combine grain loss, or to vehicle operating conditions, such as hours worked or system failure.

Secondly, we are concerned with *Control Systems* that will automatically control a vehicle operating parameter to within limits pre-set by the operator. An example is the control of a combine header height, or the draft or position of a plough.

In both cases, we are concerned with not only the "black box" itself but the complete system. That is, the sensors, the actuators, the wiring harness, and the interfaces with the mechanical, electrical and hydraulic components. Lastly, and perhaps most important, the interface with the operator – the display unit, the switches, and operating instructions. I will return to this theme later on, but I cannot over-stress the importance of considering the system as a whole, and not just as bolt-on equipment.

Thirdly, we are becoming increasingly concerned with *Management Systems*, that is the relationship of vehicle operating conditions and parameters to the management of the farm as a whole. Examples are the operating costs, or maintenance requirements.

The premise in all our electronics development is that farmers the world over are as interested today as much in *reducing the cost of crop production* as in the *increase of crop yield.* Electronics can provide the means of improving both. However, we must be conscious at all times that we are treading in largely unknown territory – dealing in "black art", as one of my colleagues puts it – and secondly that we cannot afford to jeopardise reliability.

If we trace the engineering development of a typical electronic system, we will appreciate the factors that are considered, and the steps taken to ensure a successful product. In this exercise, it should be noted that the Central Electronics Group of Massey-Ferguson provides an electronic systems design and development service for all Massey-Ferguson's worldwide Product Divisions (Farm and Industrial Tractors, Combine Harvesters, Engines and Hydraulic Equipment), but does not manufacture production quantities of electronic systems. Our service comprises the initial conceptual *planning* of a system, the *design* and development of the system software and hardware, the packaging, and the building and *testing* of prototypes. The *manufacture* of the final design will be assigned to an appropriate specialist by the Product Division.

### Planning

The planning of electronic systems projects is similar to that of conventional engineering projects, but it has its unique features, in that, although the design cycle may vary from one to three years, the technology in the electronics industry is advancing at such a rate that we are often starting with a technology that is only embryonic. To ignore such embryonic technology would be to

---

*Michael Potter is Director, Central Electronics Group, Massey Ferguson Research Ltd, 5735 McAdam Rd, Mississauga, Ontario L4Z 1N9 Canada*

*This paper was presented at the Institution of Agricultural Engineers, East Midlands Branch Conference, Caythorpe, Grantham, 8 January 1986.*

risk finishing the design cycle with an obsolete product, or at least, one that was not cost effective. For example, surface mount technology is rapidly becoming preferable to pin mounting for components on to printed circuit boards, particularly for medium/high volume manufacturing. The advantages are significant in terms of improved reliability and reduced cost.

Another unique feature of electronics project planning is the selling of the concept to the machinery manufacturer's staff and then to the end user, Since we are dealing with largely unknown, and sometimes difficult to grasp, concepts, it is difficult to project ahead what will be the benefits of an electronic system. The secret is to spend time in-house exploring ways and means of solving an operating problem, conducting conceptual trials, and only then, with the courage of your convictions, selling the concept. Specific milestones must be set that will enable all involved to measure progress of the development, and to build up confidence in the benefits of the final product.

At the conclusion of the planning stage, it is essential to have asked, and have had answered, some fundamental questions.

- What are the objectives of the electronic system, expressed as far as possible in quantifiable terms?
- What are the economic factors – the target unit cost, the target added value, the user benefits?
- How will the unit be sold – an integral part of the vehicle, or retrofit?
- When will it be required?
- What will be its life expectancy?

The answers to questions such as these are essential to guide the designer in his work, if the final product will truly enhance performance and not be a problem, of whatever magnitude, to the end user.

### Design and development

At this stage, a combination of engineering skills are initiated, all co-ordinated by a Product Engineer, whose responsibility is to ensure that the electronic system's objectives are met. Qualification specifications are established for the operating environment of the system, together with the physical and human interface parameters, prior to development of the software and hardware.

Electronic systems engineers are charged with the circuit design and initial component selection, using computer aided design methods for both the design and analysis of the circuits. In the case of micro-processor based systems, the algorithms are developed and encoded. Prototype breadboards are fabricated and subjected to operational analysis in the laboratory.

In parallel with this activity, the enclosures are being designed, including any display units, and prototypes constructed. This activity, together with the selection of appropriate sensors, actuators, connectors, enables a complete system to be prepared for environmental and field testing.

### Testing

The conventional engineering environmental testing is conducted in laboratory conditions with exposure to extremes of heat and cold, hostile chemicals, moisture, dust, and shock and vibration. In addition, electronic systems have to be tested for susceptibility to electromagnetic radiation, and for electromagnetic interference with other equipment. Universal standards have yet to be adopted throughout the farm machinery industry, but military specifications are often used as a base.

The crucial testing is conducted in the field, on both Company owned vehicles and those of selected end users. The testing is conducted in as wide a variety of climatic and operating conditions as possible, with careful follow up of results recorded.

### Production

At this stage, we have a proven prototype design, and the process of preparing for manufacture and market launch begins to accelerate. The manufacturer of the unit must be selected, not only upon satisfactory commercial terms, but also upon a confidence that a quality product will be supplied.

Factory and dealer set-up and service equipment must be arranged, together with training and operator manuals. Training in the correct use, and diagnosis of faults, of the complete electronic system is vital, if the end user is to derive its full benefits.

Inevitably, modifications will be required to the system throughout its life as improvements occur, or as expanded uses are demanded. The Central Electronics Group regard those as a continuing responsibility.

This brief run through the key stages of an electronics system development has only glossed over the many man-hours of activity aimed at ensuring that the end user does not suffer from operational problems, but increases his productivity. It is our aim to ensure that we have minimised the possibility of system failure, either by careful attention to design or to the manufacturing and marketing process. You will be interested to know that we design to Mean Time Between Failure levels of 20,000 hours.

Let us now turn our attention to some of the electronic systems that are available today on farm vehicles, and what benefits they bring, and then to a glimpse into the future.

## Monitoring systems

There is a trend towards the replacement of conventional mechanical and electro-mechanical gauges by solid state electronic displays. The advantages are higher reliability, elimination of mechanical drives, grouping of data in a single display panel, and possible cost reduction. One of the potential disadvantages is reduced visibility under certain lighting conditions, depending upon the type of display used – LCD, Vacuum Fluorescent, CRT, etc. There is also the temptation to produce a rainbow effect of many coloured digits and symbols that may detract from the prime purpose – to give sufficiently accurate information at a glance.

In addition to providing vehicle operating information, and particularly of the engine – speed, oil pressure and temperature, water temperature, etc. – electronic displays may be programmed with pre-set values, which, when exceeded, will trigger off an alarm, either visual or aural.

The key to being able to provide a suitable electronic system is often the availability of an adequate sensor. For example, the availability of radar based true ground speed sensors now enables the operator to know his vehicle speed with far higher accuracy than hitherto, and also provides an essential input controlling vehicles.

Tractor Monitoring Systems, in a variety of arrangements and efficacies, are now available as standard or optional fit for all major brands of tractors.

In the case of trailed implements, or machines, such as seeders, planters, fertiliser and herbicide/ pesticide machines, electronics have been on the market for some time, particularly monitoring the flow of material. The sensors monitor the shaft speed, or fluid speed, and warn if the speeds fall below a predetermined level. The driving force for the development of such systems was the need for the operator to know if he was applying the material or not. The next question for the operator is how much material is being applied, and then can it be varied on-the-go. We shall look at those aspects later on.

Combine Harvester Monitoring Systems have also been on the market for some time. The driving force in this case was the number of shaft speeds that needed to be monitored, and adjusted relative to one another, to ensure optimum threshing. The Monitoring System typically also provides engine parameter information. An additional monitor that is proving to be cost effective is the Grain Loss Monitor, monitoring the grain loss in two or three locations in the machine. Either pad or tubular sensors may be used, sensitive enough to detect the striking of individual grains.

Since the combine harvester operator is nowdays located in a cab, isolated from the "feel" of the vehicle, additional alarms are provided to warn of malfunctions, and to advise for the need of pending action, such as emptying the grain tank.

## Control systems

This is the area where electronics really demonstrates its utility. The computing power and speed of today's microprocessors, coupled with their reducing size and cost, enables us to reduce significantly the amount of effort required for a given task. Furthermore, the task can be performed with greater accuracy, more consistently, and for longer periods, without the need for highly experienced operators. If all this sounds too good to be true, then we must admit that a certain amount of scepticism is justified. True closed loop Control Systems are still in their infancy in the farm vehicle world. However, some Systems are already on the market, but many more are in the pipeline.

Current examples are Electronic Draft Control Systems, Tillage Depth Control Systems and Combine Header Height Control Systems.

Draft Control Systems sense the draft force, usually on the lower links, and send a signal to the hydraulic system, causing the mounted implement to raise or lower to maintain a constant draft. In principle the same as the conventional mechanical system, but with a higher degree of accuracy and response time.

Depth and Height Control Systems on the market today may use ultrasonic sensors to determine the distance from a reference point on the machine to the ground surface, with distinction being made between the true ground surface and trash lying on the surface. The prime advantage of these sensors is that they are not in contact with the ground, and therefore not subject to wear.

## Training

It is essential that dealers, and vehicle owners and operators, receive adequate training on the operation and interaction with the electronic systems, and particularly the control systems. Although the designer has made every effort to make the system user-friendly, and indeed, even to tuck away the "black box", there still remains a display and a set of switches, which not only look a little out of place on a farm vehicle, but which apparently enable the operator to perform more effectively – or so the advertising says!

It should be noted here, that "more effectively" may mean both more conveniently, that is, less fatigue, and also more performance, that is, less input or more output. The distinction is important in tailoring the training. The performance enhancement is what the customer is paying for, and he must be shown how to obtain the full benefits. These benefits may accrue from operating the vehicle in a non-traditional manner. For example, with the Header Height Control System, it is necessary only to set the required height of cut, from a control in the cab, and let the automatic control take over. This can seem a little unnatural to the operator who is used to continually adjusting the height whilst driving.

"Hands-on" training in the field is certainly effective, but techniques are now becoming available to have simulated training, utilising computer programmes, in a similar manner to aircraft pilot training. This is not to imply that a tractor or combine operator will require a pilot's licence in future, but the training technique may be very appropriate.

## Servicing

Most electronic systems are designed for factory service only – in many cases, with the cheaper units, to be thrown away. It is essential therefore that the vehicle operator and dealer are able to distinguish between a genuine fault of the electronic unit, and a fault in the wiring harness or connectors, or in the sensors or actuators. Many electronic systems, particularly the control systems, are being designed today with self-diagnosis features. This will allow a preliminary identification of the fault area, and of the appropriate remedy. The experience in the electronic system supplier industry is that the majority of units returned for repair are serviceable.

Electronic diagnostic units for vehicle and engine repair and maintenance are available in a variety of specifications and functions. The compactness of many of these units makes them convenient for the dealer to carry to the vehicle, instead of hauling the vehicle to the workshop, with significant saving in downtime.

## Future opportunities

The control system is the area where we are likely to see the most progress and benefits in the next few years. If we visualise a tractor/implement, or a combine harvester, as a mobile processing factory – in the first case, processing soil, seeds, fertilisers, and in the second case, processing grain and straw – then we realise that the objective is to measure a variety of inputs and outputs, and control the relationship between them with predetermined limits. As always in Engineering, there will be compromises to be made to achieve an optimum for any given set of conditions.

The vehicle operator is constantly juggling these inputs and outputs, based upon information received by his senses:

- The sight of instrument signals (engine and mechanism speeds, temperatures, pressures, etc) and of visual signals (obstructions or changing conditions ahead, position of mechanism elements, appearance of the furrow or swath etc);

- the sound, or feel, of the engine or mechanisms.

These sensory signals, when coupled to experience, cause the operator to take actions to control the process. However, today, the operator is often shielded by his cab from some of these signals, and also may not possess the experience acquired by his predecessors or forefathers.

The memory and rapidity of computing power of microprocessors can partially remedy these shortfalls.

### Tractors

Electronic control of the precise amount and timing of fuel injected into the engine will enable the fuel consumption/torque/speed characteristics to be specified to a particular profile, thus enabling the operator to select targets of economy, or power, or speed of operation, according to the prevailing conditions.

Multi-gear ratios, or continuously variable transmissions, will be controlled electronically to always maintain a given vehicle speed, for pre-set targets of economy or speed, for a given load.

These two features, coupled together, can interact with the linkage control of a mounted implement. With such an integral system, the operator, or farm manager, will determine which factor (economy or speed) should have priority, and the electronic system will then automatically maintain the field operation to those limits.

All that remains for the operator is to ensure that the vehicle is in a good service condition, is fuelled, and then steer it – but maybe not!

For predictive diagnostics, the memory of the control system microprocessor can either prompt the operator for upcoming routine maintenance, or the information can be down-loaded into a central data bank at the farm, or dealership, for analysis of operating conditions and costs. If an upward trend in operating costs is noted, it may prompt the need for overhaul of specific vehicle components – injectors, piston rings, seals, etc.

With reference to steering, we have all heard, and maybe seen demonstrations, of driverless tractors, but today their reality is approaching, albeit only under selected conditions. Cultivating large fields, for example, can result in significant wastage of fuel, seed and fertiliser, through overlapping. This has prompted research into cost effective means of determining the precise location of a vehicle in the field, and controlling its movement along a predetermined path – not necessarily a straight line. Practical methods, now being developed, include satellite tracking, pattern recognition using video cameras, inertial guidance, and radio beacons.

### Implements

Mounted implements, such as ploughs and cultivators, will be more effectively controlled through the previously mentioned integrated linkage system. Other implements, such as semi-trailed ploughs, or loaders, will be programed to follow a sequence of operations automatically, from a central microprocessor mounted on the tractor.

Trailed implements, and particularly machines such as seeders, planters, fertiliser spreaders, sprayers will be operated with automatic control of their key parameters – depth of planting, rate of application, mix and concentration of chemicals. The driving force, again, is economics.

One of the issues that has yet to be resolved by the farm machinery industry is the standardisation of signal transmission and connectors. We need standards, similar to those that exist for three point linkage, pto drive and hydraulic couplings, to enable universal attachment of a variety of implements.

### Combine harvesters

Although the combine harvester is a complex machine, with its design and operation being perhaps more art than science, it is equally susceptible to automatic controls. Indeed, one could argue that there is a greater need to apply them, as there are more quantifiable benefits in terms of increased productivity.

The principles of engine/ transmission, and steering control, will be applied as successfully to the combine harvester as to the tractor.

The operating parameter of header height control is already automatically controlled electronically. The interesting new development is in the area of automatic forward speed and threshing control, relative to grain loss.

Finally, let me mention farm management systems, whereby the tractor/implement system is linked to the combine harvester system, to give the farm owner or manager the potential control over the complete farm operation.

Assuming that the vehicle control systems are falling into place, the missing elements are a central recording system for all operating data, and the availability of a widely based advisory service. Help is at hand. More and more farmers, dealers, manufacturers, commodity markets, meteorologists etc. are being hooked up together on computer networks. Much of the information that is received through the network, and there is a lot of it, needs careful consideration before taking any operating decisions. To assist in this process, a recent development, that shows considerable promise, is that of Expert Systems. These are special computer software applications that are capable of carrying out reasoning and analysis functions in specific subject areas, at proficiency levels approaching that of a human expert.

## Conclusion

I trust that all the foregoing does not leave the impression that we are entering into the world of push-button, robotic, farming. Farming, crop production, must always remain in earth-bound occupation, but we, as agricultural engineers, must always take advantage of any technology that can make the farmer's life more convenient and profitable. I submit to you that electronics, carefully applied, is just such a technology.

# Putting theory into practice

## A W Galloway

### Introduction

OVER the last ten years, the output capacity of agricultural fixed equipment has grown considerably. This is due to increased arable areas on the farm and the advent of cooperative organisations coupling output from several cooperative members into one central drying and storage installation.

The scale of traffic movement has ensured that cooperatives increase their intake rates radically, so that currently intake capacities of 100 to 200 t/h have become the norm, while even farm installations are demanding 100 t/h for intake.

This in turn affects the cleaning equipment, where rates at intake require 100 to 200 t/h and on farms 50 to 100 t/h.

Drying capacities have similarly increased; crops such as rape and peas necessitate an increase in drying capacities because of slowness in drying. Whereas in the past, the farm dryer was capable of 1 to 5 t/h, we have seen a quick transition through 5 to 10 t/h up to 20 to 30 t/h. Some cooperatives have capacities of up to 60 t/h, with the largest single column dryer in this country capable of 86 t/h continuously 24 hours per day.

These outputs for dryers are normally based on drying wheat from 20% to 15% moisture content but few of the dryer manufacturers are able to test all the models in the range of the dryers they offer; the performance figures for the whole range may be based on one model's test figures, other models not even having experienced UK conditions before. We can consider the specifications as being theoretical. Determination of suitable dryers for the performance demanded is, therefore, by interpolation. Where, in the past with a 4 t/h output, errors in predicting performance were relatively small, when we are dealing with 30 t/h, these margins of error can be drastic. What happens when the customer wants to dry rape, linseed, peas, oats, malting barley and more often for us currently in the export markets, rice, soya, sunflower and maize, under differing climatic conditions?

*A W Galloway is the Chief Engineer of Law-Denis Engineering Limited. He has been developing and performance testing his company's crop drying and storage products for the past 12 years, both in the UK and overseas. This paper was presented at the Institution of Agricultural Engineers, Scottish Branch Conference organised in conjunction with the Crop Drying Specialist Group and held at Grangemouth, 12 February 1986.*

In practice, the conditions in which the dryer performance was calculated rarely occur, but few users realise the extent to which a dryer's performance is affected by the actual conditions imposed.

### 1 Moisture content

For the purpose of simulation and selection this is often considered to be finite; in practice it is variable. Therefore, when input and output moisture contents are spoken of, it must be realised that we are dealing with an average moisture content.

Sampling is very important in obtaining a true average, moisture contents must be recorded at regular intervals to be certain of the true average, and to provide written records on which correct decisions can be made regarding alterations to the flow of grain through the dryer.

### 2 Effect of average input moisture of 17.5% instead of 20%

For a number of years prior to this harvest, average input moisure contents have been far less than 20%.

**Capacity of the dryer**

Assume we have a dryer rated to give 20 t/h output of wheat, drying from a moisture content of 20% to 15%. This is equivalent to removing 1250 kg $H_20$/h.

If the input moisture content is reduced to 17.5% then 30.3 kg $H_20$ has to be removed per dry tonne.

If we look at a typical thin layer drying curve for wheat (fig 1) we see that it gets more difficult to dry as the moisture content reduces.

Therefore, in practice, the dryer originally capable of an evaporative capacity of 1250 kg $H_20$/h is reduced, because it takes longer for the grain to give up moisture. Our own tests reveal that we can assume that this reduction is 25% for this moisture range. The dryer now is capable of removing 938 kg $H_20$/h and has to remove 30.3 kg $H_20$ per dry tonne. The new output is therefore 30.9 t/h.

**Cooling**

Because the air temperature is constant and there is less moisture to remove, the maximum grain temperature reached is increased. As the input moisture contents are low, it often corresponds that ambient air temperatures during the harvest are high. For the 1984 harvest, the ambient air temperatures recorded were often 25 to 30°C. Coupled with the increased throughput of 30.9 t/h, the cooling will inevitably be insufficient.

In practice, in a mixed flow continuous dryer, one cooling section is required per 5 t/h to obtain cooling of 7° to 10° above ambient air temperature. Considering the ambient air temperature was 25° to 30°C, this temperature is a long way from the target of 15°C for long term storage. Grain which is destined for Intervention, would not be acceptable straight from the dryer because of this high temperature (table 1).

**Table 1 Grain temperature for Intervention Storage**

| *Period* | *Max temperature acceptable, °C.* |
|---|---|
| August | 24° |
| September | 22° |
| October | 20° |

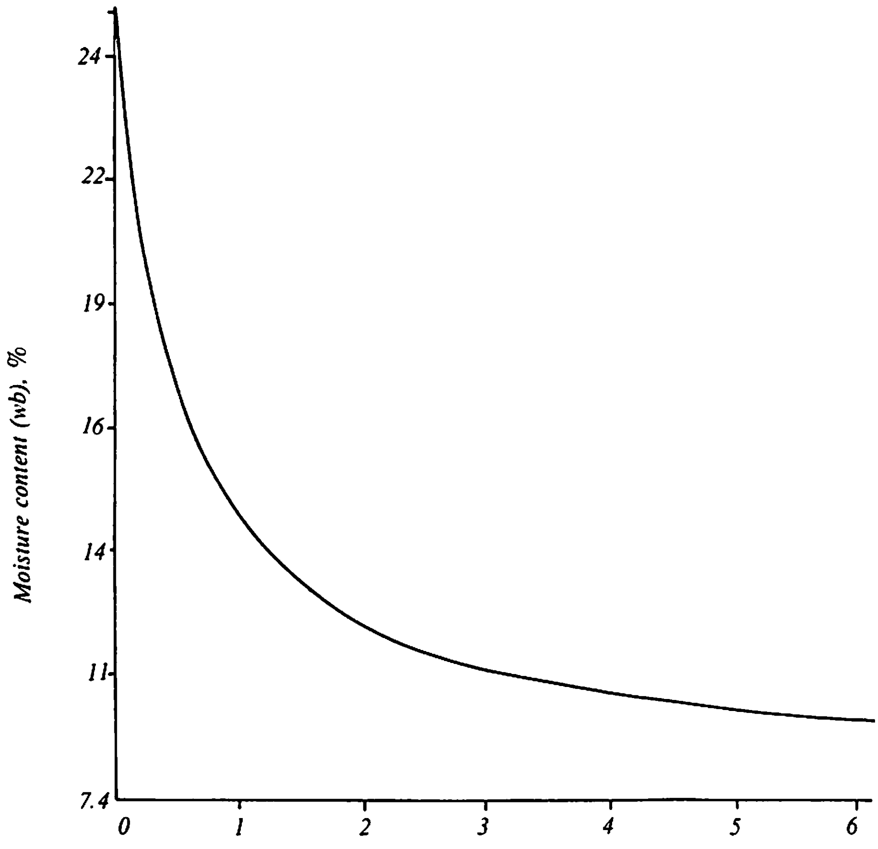



*Fig 1 Thin layer drying curve for wheat using an air temperature of 54°C*

Our increased throughput requires at least 2 more cooling sections, but apart from the reduction in output this would cause, it is far more efficient to cool in the store slowly than subject the grain to thermal shock that could be given in the dryer.

The alternative which most operators rarely consider is to reduce the throughput to the level for which the dryer was designed, in this example, 20 t/h. This is simply achieved by reducing the hot air temperature. If we look at the chart of computer simulated evaporations (fig 2), it can be seen that the evaporation rate is almost directly proportional to the temperature applied to the grain.

**Cleaning**
Drying installations are equipped with grain cleaners before drying, after drying, or both. Cleaning before drying is essential to remove straw chaff, stones and other impurities, to reduce firstly the fuel consumed unecessarily drying impurities, and secondly the waste materials which can increase the fire risk. Cleaning after drying is required to obtain a sample which is suitable for the market into which it is to be sold.

If one or other of these cleaners is directly involved in the filling or emptying circuit of the drying plant, then because of the increassed output of 30.9 t/h, his 20 t/h cleaner may not be able to cope. In the worst case, this will result in depositing far more straw and chaff into the dryer because he will be required to fit screens with larger holes to keep up with the output, defeating the object of the pre-cleaner.

**Conveying equipment**
Unfortunately, due to fierce competition, many conveyor manufacturers are forced to design their conveyors with very high speeds and high percentage filling. This enables outputs to be achieved but there is no room for expansion.

Now that the throughput of the dryer has increased from 20 t/h to 30.9 t/h, the operator finds that his conveyors cannot keep up with the dryer. If the dryer runs out of grain, most dryers are designed to stop discharging and turn off the source of heat. The result would be that it could take up to 45 minutes for the grain temperature to reach the level it was before the stoppage, and hence stability.

The moisture content leaving the dryer rises, causing the operator to over-correct and, thus, losing maximum performance of the dryer. In addition, fuel is wasted in returning the dryer to stability and the grain temperature to its previous level.

In practice, we find more time is wasted on drying plants due to stoppages on elevators, conveyors and perhaps cleaners, than due to any other factor. Operators are not aware of the effect this has on output and fuel efficiency.

## 3 Effect of average input moisture content of 25% instead of 20%

The past year of 1985 has reminded operators of the need to correctly choose equipment. Certainly for 8 years or more, moisture contents of 20% and less were the accepted norm.

Many dryers and cleaners available now were not imported 3 or 4 years ago, and users had far less tonnages to deal with then.

**Capacity of the dryer**
Taking our example of the 20 t/h dryer; the evaporation rate would normally be 1250 kg $H_20$/h. Again, looking at a typical thin layer drying curve, grain with an input moisture content above 20% is dried relatively easily, much of the moisture being free surface moisture. The dryer therefore, is, not retarded by the moisture movement in the grain, but assisted by it. For an input moisture content of 25%, a dryer's evaporation performance is increased by 5% or more. The dryer is therefore capable of 1312 kg $H_20$/h but has to remove 133.3 kg/$H_20$/dry tonne. The new output is 9.84 t/h. This has the effect of doubling the residence time of the grain in the dryer as the grain is moving very slowly. The tonnage of grain to be dried has not decreased and the operator is now faced with greater drying times than he expected. The pressure is now on!

**Cooling**
One good piece of news for the operator is that now that the output has reduced to 9.84 t/h, the cooling of grain is improved. However, it is interesting that in 1985 during August and September the Home Grown Cereals Authority reported very high rejections of grain for Intervention due to grain being too hot or too wet. These two causes accounted for nearly 63 per cent of all

barley rejections and 75 per cent of wheat (table 2).

### Conveying
As a result of the increased moisture content, there is more chance of blockages in the dryer column. The operator must pay particular attention to this. Often dryer discharge mechanisms do not promote the flow of wet and dirty parcels of grain down the column. The operator needs to check his grain temperature for signs of abnormal increases which may indicate a blockage. Special equipment is available to assist him which will be described later.

The wet grain handling systems also suffer from this increased moisture content to the extent that conveyors and elevators cannot deliver the grain at the rated output. Nearly all manufacturers base their capacities on dry grain. However, grain with a moisture content of 25% will not flow, pipework and fittings become quickly blocked with wet dust, easily reducing the flow of grain. If the dryer loses its supply of grain, then both output capacities and fuel efficiencies are lost.

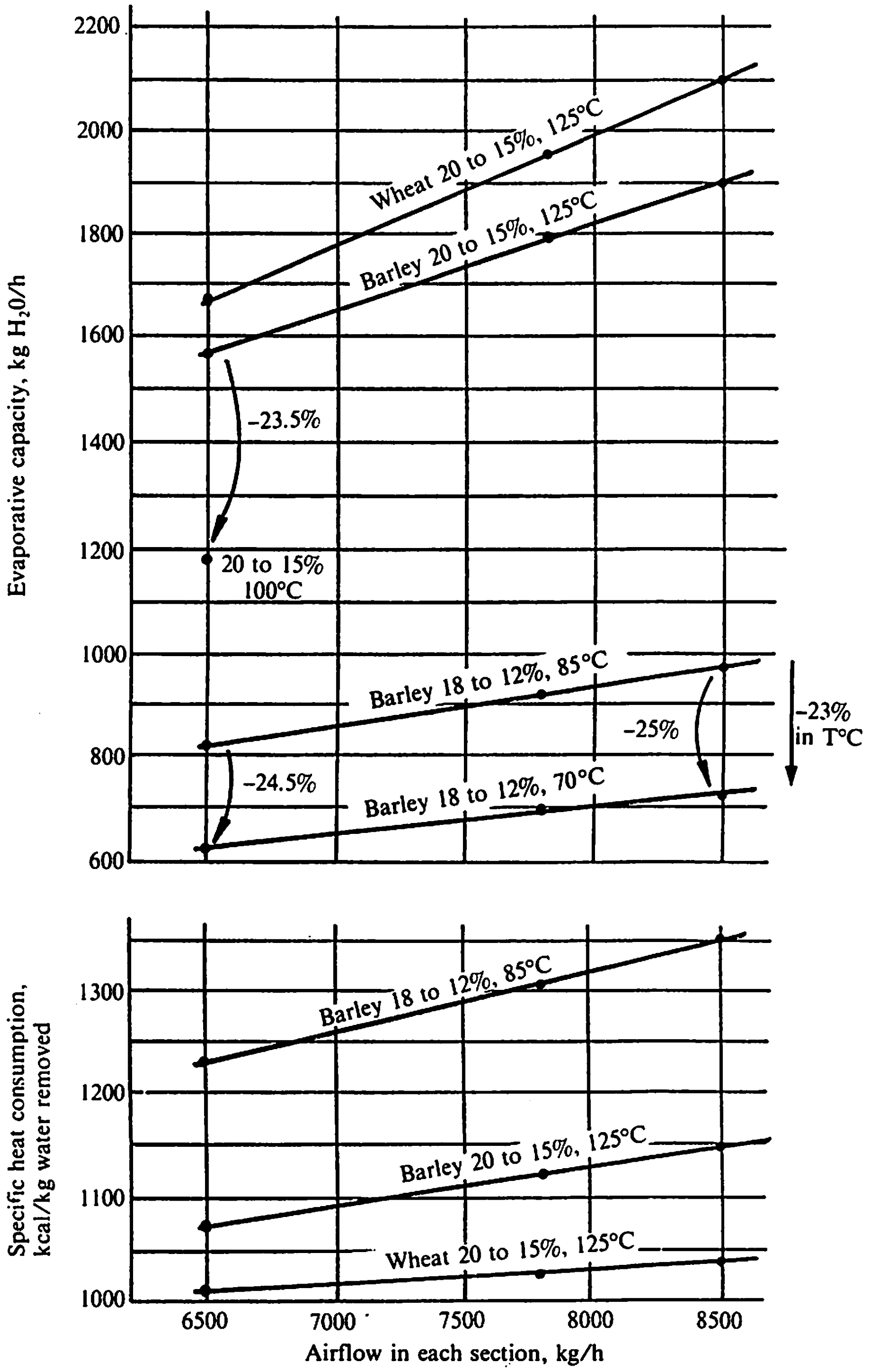



*Fig 2 Simulation of mixed flow dryer performance*

### Cleaning
Cleaning of grain prior to drying is very important with high moisture content grain. Material such as straw chaff and unthreshed heads, if not removed before entering the dryer, become dried out and separated in the dryer, thus increasing the risk of fires in the dryer.

With many cleaners in 1985, operators found that a 100 t/h capacity was reduced to 60 t/h because of the increased moisture content. Grain with a moisture content of 25% and above will not pass through the normal screen sizes, causing problems due to the pressure being on to increase output as much as possible. Larger screen sizes were required but many operators did not have a larger screen for pre-cleaning, because they had not experienced wet grain like this before. Consequently, some operators bypassed the cleaner altogether, whilst others used the largest screen available, allowing impurities to pass through.

## 4 The necessities of correct moisture measurement

### Temperature correction
The single most important piece of equipment required with a grain dryer is a moisture meter. The client is quick to condemn a dryer's performance based on the measurement he has made with his meter. So many times we find the quick testers are used, with a total misconception on how they should be used, calibrated or maintained.

How many times have we seen the sample of grain being ground in the "Moulineaux" until it is red hot? Placed in the faithful "Marconi" and the moisture content announced with glee that still the dryer is not getting the grain down to 14%.

When we mention that a temperature correction should be made, we see the operator look at his thermometer hanging on the office wall and announce "of course I have made the temperature correction." Nobody has ever told the operator that the correction should be made for the temperature of his sample not that for the office wall.

Even meters with automatic temperature correction require correct use, since the first sample put in it serves to heat the sensor only. The correct reading is not obtained until a second sample is placed in the cell.

**Table 2 Causes of rejection of grain at Intervention Stores**

| | *Barley* | | *Wheat* | |
|---|---|---|---|---|
| | *No of rejections* | *% of all rejections* | *No of rejections* | *% of all rejections* |
| Moisture | 1407 | 41.04 | 338 | 26.74 |
| Temperature | 738 | 21.53 | 627 | 49.60 |
| Total impurities | 384 | 11.20 | 21 | 1.66 |
| Broken grains | 170 | 4.96 | 40 | 3.16 |
| Grain impurities | 235 | 6.86 | 2 | 0.16 |
| Misc. impurities | 102 | 2.98 | 24 | 1.90 |
| Other cereals | 37 | 1.08 | 4 | 0.32 |
| Specific weight | 122 | 3.56 | 49 | 3.88 |
| Live pests | 125 | 3.65 | 60 | 4.75 |
| Other reasons (1) | 106 | 3.09 | 99 | 7.83 |
| Total | 3428 | 100.00 | 1264 | 100.00 |

*(1) Includes rejections for two or more reasons, smell, ergot, shrivelled grains, foreign matter and grain damaged by drying.*

**Representative sample**

Sampling has always been a subject of considerable concern in bulk but, when applied to dryer operation, the operator does not attempt to obtain a representative sample. He probably takes one handful from an elevator boot as soon as a discharge commences, and another from the back of the trailer as it tips into the intake pit. Whilst the errors which occur in this method of sampling may give an apparent advantage or disadvantage to the dryer performance, a more consistent approach is required to get the optimum performance from the dryer.

**Over-correction**

Often these days, grain is being dried for Intervention Storage. The owner of the grain knows that no grain sample must have a moisture content above 15% when offered to Intervention. He tells his manager to make sure no grain has a moisture content above 14.5%, his manager in turn tells the operator no sample must have a moisture content above 14.0%. The operator for fear of his job, applies his own factor of safety and settles for a moisture content of 13.5%. The operator is unaware of the affect this has on the output of the dryer.

**Effect on the dryer performance**

Each of the preceding points generally lead to an unnecessary overdrying of the crop. In incorrect temperature compensation alone when the operator measures the output moisture content, where generally the temperature of the sample is greater than his office wall, the error can be 1%.

Returning to our 20 t/h dryer, capable of 1250 kg $H_20/h$ when reducing the moisture content from 20% to 15%. If the grain moisture content was actually reduced to 14%, then 75 kg $H_20/t$ have had to be removed. Thus, the output has dropped to 16.6 t/h. In addition, remembering the thin layer drying curve, it is more difficult to remove this moisture below a moisture content of 15%. Our experience for this moisture range, and our computer simulations, shows we can expect a reduction in performance of approximately 5%. Therefore, the evaporation rate would be 1187.5 kg $H_20/h$, giving an output of 15.8 t/h. The output is now 21% less than the output which the client selected when designing his plant.

## 5 Protection against possible fires

The risk of a fire in a dryer is no more or less in one design than another. Fires occur in all types of dryers. One common misconception is that the grain catches fire by spontaneous combustion. This is not true. Neither is it true that the temperature of the hot air is capable of setting fire to the grain.

What is true is that often drying plants are designed and operated without ever considering the potential fire risk involved.

There are two main ingredients for a fire in wheat, barley, oats or rape (some materials such as sunflower can ignite because of inflammable gases given off during wet storage):

(1) material to burn — that is chaff straw etc;
(2) an ignition source — sparks or dust layers which have never been cleaned off, carbon deposits around the burner, and many others.

The availability of material to burn brings us back to the effective pre-cleaning before drying. In 1985, dryers were at great risk because of the high moistures content of incoming grain. Operators either bypassed the cleaner or put such large screens in that they were effectively useless. Depending on the filling arrangements into the dryer, this straw and chaff can be separated to one side or other of the filling point. Because the dryer is running slower than expected, this chaff and straw is held in one place for long periods. It becomes very dry and volatile, it does not flow as well as the grain, and dependent on the discharge mechanism in the dryer, may not flow at all.

It only needs a spark to ignite it. The spark can be provided in a number of ways, most common being straw and chaff ingested in the burner, but this is not the only possibility. Does it make sense then to site the intake pit right alongside the burner?

One manufacturer has decided to have his air intake on top of the dryer, recognising this source of ignition, but while this may reduce the fire potential, it cannot eliminate it. They must not ignore the possibility of sparks from flaking refractories or the odd bird's nest or two.

It is important, therefore, that the pre-cleaner is effective and operated correctly even when the grain is at 25% and more.

**Fire detection**

There have been smoke detector systems fitted in some dryers, the success of which depends on how often the operator can afford to clean the sensor. However, waiting until smoke is detected would most often be too late. Remembering that a fire risk requires a build up of straw or chaff, the operator can observe an abnormal rise in grain temperature if there is a severe build up of dry material.

Taking this a stage further, an automated detector which measures temperatures of exhaust air at different points can be installed. These points are scanned automatically and compared with a preset alarm level. A small rise in temperature above the normal temperature gradient for that product in the exhaust can sound an alarm, and switch off the burner. The operator is then advised exactly at what point the temperature has risen and can personally check the dryer for a build up of straw at that point. This information is given to him long before there is ever a risk of fire.

## 6 Factors affecting fuel consumption

Although fuel used for drying is relatively cheap compared with the total costs per year for growing, harvesting and storing grain, the fuel consumption is often a factor of concern at the time of selecting equipment. Operators do not fully understand how they affect the consumption by the way they operate the plant.

### Moisture measurement

Obviously correct measurement of moisture content is extremely important because over-drying will put the dryer into a regime of high specific fuel consumption as it becomes more difficult to remove the moisture from the grain.

### Start-up fuel consumption

Continuous flow dryers should be operated continuously; often the dryer is selected on an output which is greatly exceeded in practice. Added to this, the operator is being asked to dry rape in the morning, milling wheat in the afternoon and back to feed barley at night. Consequently, the dryer is forced to operate like a batch dryer and suffer increased fuel consumption due to repeatedly heating from cold, the dryer and its contents.

During a test we conducted covering 11¼ hours of continuous drying, the specific consumption including the start-up period, was 1560 kcal/kg of water removed. However, the specific consumption for the continuous period alone, starting after stabilisation was reached, reduced to 1200 kcal/kg of water removed; a 24% reduction.

### Alteration of airflow

If we return to the simulated evaporation rate (fig 2), we can identify two important relationships with alteration of airflow.

(1) For a given hot air temperature, increasing the airflow from 6500 kg/h to 8500 kg/h increases the evaporation rate from 1670 to 2100 kg/h.

(2) For a given hot air temperature, the same increase in airflow increases the specific fuel consumption from 1010 - 1070 kcal/kg of water removed.

For a 25% increase in output, the fuel consumption increases by 6% only. These factors have led to the development of a design of dryer aimed particularly at those installations which are drying a variety of crops such as the commercial grain dryer and the cooperative.

The schematic of the multi-mode dryer is shown in fig 3.

It is designed to run in three different modes chosen simply in the control room by selector switches.

*Mode 1 – Standard mode giving the designed throughput.* The air regulating shutter at the top of the exhaust plenum is open giving the standard low air flow. The recirculation fan at the bottom is operative, returning useful heat from the unsaturated exhaust air to the hot air chamber and thus providing up to 20% fuel economy compared with the standard mixed flow dryer.

*Mode 2 – Increased output mode.* This allows the operator to increase the output by up to 25%, for those times when he is faced with large inputs of grain when he least needed it. The sacrifice is, of course, increased fuel consumption of approxim-ately 6%. The air reduction shutter is closed in this mode — thus increasing the airflow in the dryer. The recirculation fan is still operative, providing economy from the unsaturated exhaust air.

*Mode 3 – Extra reduced air mode.* In this mode, the recirculation fan dust shutter is closed. The air is greatly reduced and does not have recycled exhaust air. This mode is used when much lighter crops are dried, such as rape, and allows the operator to easily alter the airflow from the control room.

## Conclusions

The main areas examined in this paper lead to the conclusion that modern drying and cleaning plants fall short of the performance expected from them, due to 3 factors:

a) effect of alternative climatic

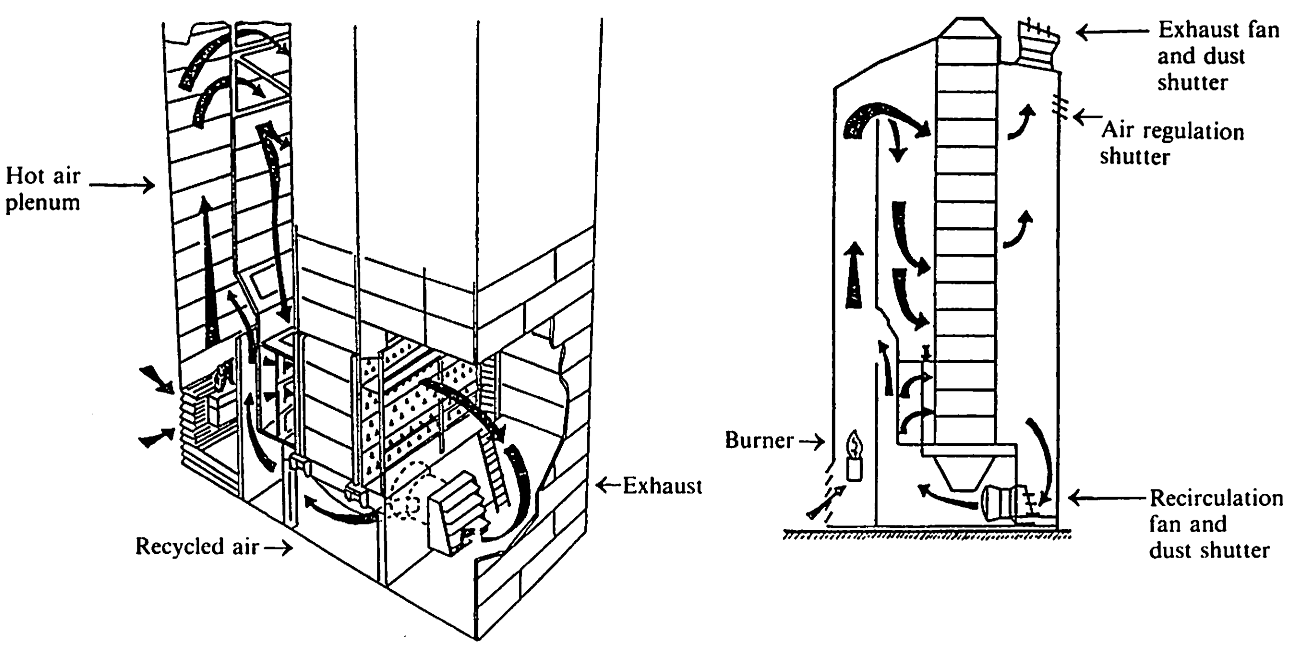



*Fig 3 Law-Denis Multimode Economiser Dryer*

conditions to those envisaged when the plant was designed;

b) ignorance by the operator of the steps to be taken to compensate for these changes;

c) lack of operational expertise, not only in the full understanding of the basic rules which apply to the processing of grain, but also in the careless operation of the equipment.

These factors, especially the first, cannot be eliminated, but their affect can be reduced by the following.

1. Designers of plant and equipment must take into account the effects of variable moisture contents and of cleanliness of the grain and assist the operator in ease of plant control. However, all these desirable objectives cost money, which the customer will not accept. Most plant designs are chosen by the price on the day. It is, however, the duty of the manufacturer, agricultural dealer, consultant or adviser to provide the customer with the true facts that concern the operation of the plant when dealing with differing seeds in extremes of conditions during the pressures of harvest.
2. The manufacturing industry, and especially the agricultural dealers, have lagged in training the customers, both purchaser and operatives, in the correct operation of equipment. Often they know little more than the customer. This is particularly true of agent/importers.

It is time for the manufacturers to lead the way in conjunction with the specialist fixed equipment dealers assisted by advisers and others knowledgeable in the field to provide programmed and clearly laid out training courses for not only their own customers, but all those who are involved in this area.

## References


**Hustrulid A** (1963). Comparative drying rates of naturally moist, remoistened and frozen wheat. *Trans Am Soc agric Engrs,* **6** (4), 304 — 308.

**Miller P C H, Whitfield R D** (1984). The predicted performance of a mixed flow grain dryer. *J agric Engng Res,* **30,** 373—380.

The Agricultural Engineer

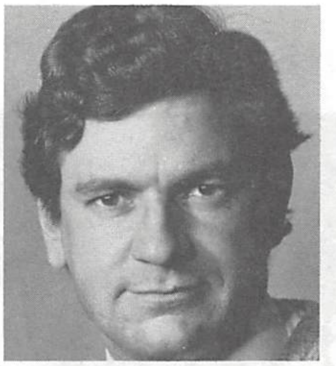
AgEng Items

# Assessment of an exhaust gas aspirator when fitted to a tractor engine

D H Rackham and M J Sharp

*David Rackham*

*Malcolm Sharp*



## 1 Introduction

THE valve timing on a conventional internal combustion engine is usually designed to give a period at the beginning of each induction stroke when both the inlet and the exhaust valves are open simultaneously. This is called 'valve overlap'. Its purpose is to improve the flow of gases through the engine: the momentum of the outgoing exhaust gases and the scouring effect of the incoming fuel/air mixture help to remove the spent combustion gases from the combustion chamber. Inevitably the descending piston draws some of the gases in the exhaust manifold back into the cylinder. This may be detrimental to the subsequent burning of the fuel/air mixture.

The 'Gefarator' exhaust aspirator when fitted to an engine, either petrol or diesel, is claimed to reduce the harmful effect of these 'recycled' exhaust gases by diluting them with air (Autosec).

## 2 Description of aspirator

The device, in its simplest form, comprises a 0.47 metre length of stainless steel tube, the diameter of which is stepped. At the narrow end of the tube, a non-return valve is fitted, and the other, larger end, is screwed into a finned connecting piece which, in turn is screwed into a tapped hole in the exhaust manifold. On some engines, variations on this basic theme are used: either branched connections to the manifold or twin valves at the 'inlet' end.

The device operates by utilising the negative pressure pulses generated in the exhaust system as the various exhaust valves open and close. These pressure pulses travel up the 'Gefarator' tube, allowing air to be sucked in from outside through the non-return valve when the pressure in the narrow end of the tube is below atmospheric. When the pressure is above atmospheric, the non-return valve shuts. Hence, there is a net flow of air down the tube, which dilutes the exhaust gases. Additional benefits claimed are a water injection effect, reduced carbon build-up, and a smoother and more flexible engine. According to the manufacturers, the device is more effective at low engine speeds.

The Scottish Institute of Agricultural Engineering was asked by the local distributors for the device if we could fit and test a 'Gefarator' on a tractor engine. Though they have been fitted to diesel engines in light vans and cars, none had yet been tested on a tractor engine. These being inherently slow revving, the benefits might be considerable.

## 3 Test procedure

A representative from the local distributors for the device fitted a 'Gefarator' to a David Brown 996 tractor. The specification for this engine is given in Appendix A. A hole was drilled and tapped into the centre of the exhaust manifold, and a single 'Gefarator' tube installed, though with twin non-return valves fitted into a 'Y' connecting piece at the 'inlet' end (fig 1). The tractor was already fitted with a fuel flow meter, so it was possible to make precise measurements of fuel consumption, using a hydraulic dynamometer on the power-take-off (pto) as the load. A torque transducer was coupled between the tractor pto shaft and the dynamometer to give accurate readings for torque, power and rotational speed.

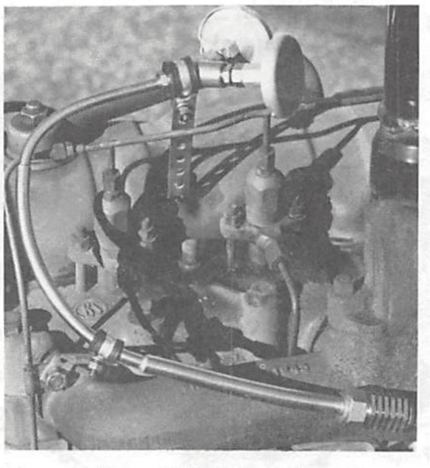


*Fig 1 The 'Gefarator' exhaust aspirator fitted on the David Brown 996 tractor*

The tractor engine and the dynamometer were thoroughly warmed up before each test. Following this the calibration of the torque transducer was checked. Then the tractor hand throttle and the dynamometer brake were adjusted to give the desired power at the desired engine speed. This setting was held for about twenty minutes, at the end of which the quantity of fuel used was recorded from the fuel flow meter.

We measured fuel consumption both with and without the 'Gefarator' fitted at nine different engine settings — ie three engine loads at three engine speeds. The speeds selected were 1333, 1800 and 2166 rev/min and the loads corresponded to

*David Rackham is a Sales Executive for Longman Cartermill, of St Andrews, Fife, Malcolm Sharp is on the Scientific Staff at the Scottish Institute of Agricultural Engineering, Penicuik, Midlothian.*

20, 30 and 40 kW at the two higher speeds, and 10, 20 and 30 kW at the lower speed.

Initial runs were at an engine speed of 1800 rev/min and the three power settings without the 'Gefarator' connected. Then these runs were repeated with the device connected. This procedure was repeated at 1333 rev/min and again at 2166 rev/min. In addition, maximum power and torque were measured with and without the 'Gefarator'.

## 4 Results

Fuel consumption was measured in litres per hour but converted to specific fuel consumption (fuel used per unit power developed, kilogram per kilowatt hour) as this is a more meaningful indicator of the efficiency of the engine. Table 1 shows the results.

Specific fuel consumption, with the 'Gefarator' fitted, was improved at five of the nine engine settings. There was no significant improvement at any of the settings at the higher engine speed (2166 rev/min) but at the two lower speeds, only one setting showed no improvement: 30 kW at 1333 rev/min. Maximum power at the pto was increased slightly when the 'Gefarator' was fitted, though maximum torque was reduced. The accuracy of the measurement was estimated to be ±1%.

**Table 1 Specific fuel consumption (kg/kWh) for DB 996 at different engine speeds and pto power outputs, with and without 'Gefarator' fitted**

| *PTO power, kW* | *Engine speed, rev/min* | *PTO speed, rev/min* | *Specific fuel consumption, kg/kWh* | |
|---|---|---|---|---|
| | | | *Without Gefarator* | *With Gefarator* |
| 10 | 1333 | 400 | 0.289 | 0.282 (-2.59%) |
| 20 | 1333 | 400 | 0.239 | 0.234 (-2.22%) |
| | 1800 | 540 | 0.269 | 0.258 (-4.08%) |
| | 2166 | 650 | 0.310 | 0.310 |
| 30 | 1333 | 400 | 0.247 | 0.248 (+0.36%) |
| | 1800 | 540 | 0.241 | 0.236 (-2.28%) |
| | 2166 | 650 | 0.268 | 0.271 (+0.90%) |
| 40 | 1800 | 540 | 0.258 | 0.249 (-3.37%) |
| | 2166 | 650 | 0.264 | 0.263 (-0.27%) |

*Maximum PTO torque without Gefarator 810 N m*
*with Gefarator 795 N m*

*Maximum PTO power without Gefarator 42.0 kW*
*with Gefarator 43.0 kW*

## 5 Discussion

Our tests confirmed the manufacturers claim that the 'Gefarator' was effective at low engine speeds, with the exception of the anomaly at 30 kW and 1333 rev/min. This was very close to the point of maximum torque, the value of which was also reduced when the 'Gefarator' was connected, so it could be fairly assumed that the device was not effective in this region of very high torque and low engine speed.

A rough estimate of how much air was entrained by the 'Gefarator' was measured by placing a plastic bag of known volume over the intake and sealing it tightly around the tube. The engine was run at 1800 rev/min and the time measured for the bag to be fully collapsed. In this way, the air flow into the device was found to be, very approximately, one litre per minute. When compared with an estimate of the total amount of air passing through the engine this figure was very low — of the order of 0.1%. So any dilution effect must be very small.

The device might assist* gas flow through the engine by acting as a resonant chamber, in the manner of an organ pipe. A standing pressure wave might form in the tube, which could encourage a certain pressure regime at its junction with the manifold, which might be beneficial to gas flow in the manifold. However, such an effect would be expected to be dependent upon engine speed and tube length, exhibiting pronounced peaks in efficiency as with any resonance phenomenon.

In their advertising literature, the distributors claim that, though the running of an engine (presumably petrol) is improved immediately the device is installed, engine performance will continue to improve to a maximum after 500 miles, and thereafter will be maintained indefinitely. It would be difficult to check this as other factors might have changed over the intervening 500 miles.

## 6 Economics

Taking 1800 rev/min as representative of the speed at which the tractor engine will be working most frequently, the mean fuel consumption with the 'Gefarator' installed is improved by 3.2%, averaged over the three power settings used. Although this is not as large an improvement as the distributors claim for a petrol engine, the cost of fuel consumed by a tractor in one year is greater than that used by a passenger car, so savings are quicker to accrue. The cost of the 'Gefarator' as fitted to the test tractor is £65.00 (April 1985) so at this level of saving, the payback period would be 1172 engine hours (diesel fuel at 21.4 p/litre), which corresponds to just over a year at average rates of tractor usage (Appendix B).

The distributors claim improved efficiency after the device is run in. We wonder, however, if the non-return valves of the 'Gefarator' would be liable to blockage by dust, small bits of straw and dry grass, etc in the absence of an external screen.

## 7 Conclusions

7.1 The 'Gefarator' exhaust aspirator, in the form that it was fitted to the DB 996 tractor improved fuel consumption by an average of 3.2% taken over three different power outputs at 1800 rev/min.

7.2 There was no improvement in fuel consumption at 2166 rev/min.

7.3 These tests are only valid for the device and tractor tested. The working of the 'Gefarator' is, we suspect, very dependent upon the design of the engine (in particular the exhaust system).

## References

Autosec Engine Management Systems. A new approach to combustion efficiency, (Distributors' advertising literature). Autosec Engine Management Systems, 19 Lime Grove, Dunfermline, Fife.

## Appendix A

Specification for David Brown 996 engine:

Four cylinder, direct injection, cross-flow diesel

| | |
|---|---|
| Displacement | 3594 $cm^3$ |
| Bore | 100.01 mm |
| Stroke | 114.30 mm |
| Compression ratio | 17:1 |
| Firing order | 1,2,4,3 |
| Maximum pto power | 44 kW |

**Appendix B** Economic analysis:

| | |
|---|---|
| Price of agricultural diesel (April 85) | 21.4 pence/litre |
| Average saving at 1800 rev/min when 'Gefarator' fitted | 3.2% |
| Giving a saving of | 0.69 pence/litre |
| Representative fuel consumption of medium size tractor | 8 litres/hour |
| Giving a saving of | 5.55 pence/hour |
| Capital cost of 'Gefarator' including fitting but excluding VAT | £65.00 |
| Therefore cost recovery period | $= \frac{65.00}{0.0555}$ |
| | = 1,172 hours |

Taking, then, a typical tractor usage of 1000 hours/year, the payback period will be just over a year. This figure is very sensitive to tractor usage and the price of fuel.