THE AGRICULTURAL ENGINEER

Volume 43 Number 1 SPRING 1988

Technical progress during the Institution's first 50 years

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 £6.00 per copy, annual subscription £23.00 (post free in UK)

Front cover shows an early Clayton trailed combine circa 1938 and the current stripper header developed by AFRC – Engineering, to whom we acknowledge provision of the photographs.

THE AGRICULTURAL ENGINEER

Volume 43 Number 1 SPRING 1988

Contents

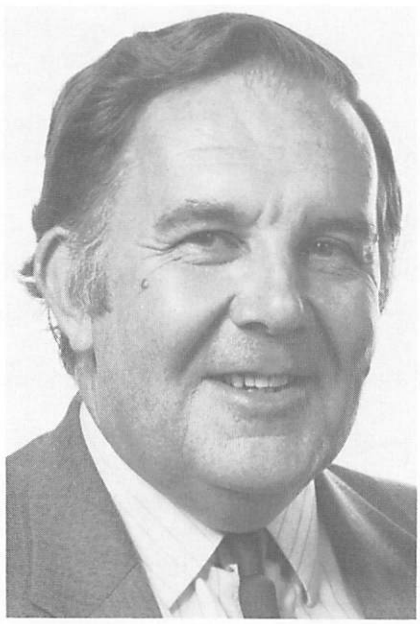
ISSN 0308-5732

Guest Editorial

Times and technologies of the Institution's first and next 50 years

The President, John Matthews

I DROVE my first agricultural tractor in 1939, just one year after the formation of the Institution of Agricultural Engineers and near the beginning of what must have been agricultural mechanisation's most hectic period of advance. In 1938 World War II was only a year away and it was that war, with dangers on the high seas threatening our food imports, that presented British agriculture with the challenge of rapidly enlarging its arable sector in a quite unprecedented way. In the North Buckinghamshire village where I lived there were, in 1939, perhaps only two arable fields in the parish, only one farm had a tractor and most of the others owned between one and three cart horses. The arrival on each of the main farms of a Fordson tractor in 1939 meant initially that the plough purchased with it was the only tool designed for tractor operation. For each of the other tasks the horse implements needed to be converted to work with the Fordson, drawbar adaptors being used between the shafts of muck carts and horse rakes and turners, and the long pole originally designed to pass between two horses on the mower being shortened and the angle changed to couple up to the tractor. Surely at this stage our farm equipment industry showed its true abilities and over the next very few years each of these farmers purchased a whole range of machines for tractor use such as disc harrows, drills, 12 ft wide drag and chain



harrows, and wide hay rakes. More than half of the fields in our village became cereal and occasionally potato land and this was typical of vast areas of the country. The first bucket-type milking machines appeared with us soon after, and despite the technological sophistication of the war machine, it was clearly a delight and enthralment of so many of living in the country that around us grew agricultural engineering with its ever-broadening application to crop husbandry, post harvest processes, livestock husbandry and horticulture. Many of the men were, of course, called up so that for the younger of us the opportunity to drive tractors and operate machines presented itself, although we had several more years to go at school. The older lads were pleased not only by that chance, but by the arrival on farms of the Women's Land Army's group of enthusiastic and hard working girls, who not only drove our tractors and machines with great skill but also did a great deal for the morale of the men and lads remaining on the farms!

Fifty years later, the reader may ask what is the significance of all this in terms of today's agricultural engineering industry. I think we learn something from drawing the contrasts and from looking at the similarities. There are many lessons to be learned from the period in between and I hope that throughout this year of Golden Jubilee of the Institution of Agricultural Engineers we shall spend a proper amount of time planning our future by learning lessons and paying due regard to our experience gained over the last 50 years. At the same time there is obviously a risk in too much backward thought and we must never forget that today is the first day of the future and it is the future which is our responsibility whether it be responsibility to our employer, our Institution, our country or our fellow men.

One clear difference between now and 1938 is that then the nation was "screaming" for more food and anything that we could do to enhance production was inevitably good. In 1988 we have surpluses and our main thrusts must be to reduce input costs while maintaining production to maximise the country's competitiveness whilst at the same time giving an equal priority to the maintenance and improvement where possible of the quality of farmers' and growers' produce. Another difference is that in 1938 machines were simple and rugged but low cost was vital and frequent repairs were a normal expectation. In 1988 the quality of design and production engineering is of great importance and not only

---

President John Matthews is also Director of AFRC's R & D work in Engineering which is mainly carried out at their Institute at Silsoe, Bedford.

individual models of equipment but a company's and even the country's reputation for agricultural and horticultural equipment will rest on customer experience of its reliability and durability. Within reasonable cost constraints, design, development and quality assurance must increasingly be seen as the priority technologies within our manufacturing industry. Finally, during the Institution's early years in World War II both the education of agriculturalists and engineers called for large numbers to be adequately trained and their knowledge to be supplemented by what became a revolution in advisory services from Government agencies. In 1988 agricultural and engineering technologies have become sophisticated to a degree unimaginable then, calling for education and training in depth and breadth only made possible by equal advances in the techniques of learning and information communication.

Despite these dramatic contrasts there are several facets of our activity which stay the same. The need for engineers to understand sufficient of the biology and husbandry of agriculture, such as inherent plant to plant or animal to animal differences, the substantial dependence on soils and environmental factors which vary over vast ranges in relevant characteristics, big differences between conditions in the many parts of the world in which we work and the vital importance of properly allowing for the farmer's skill and reasonable demands for challenge without unnecessary stress, It has always been necessary for our equipment and operating systems to be designed in a way that they work acceptably under this wide range of conditions. Similarly it is also a requirement for engineers and physical scientists to listen to and work with agronomists, livestock husbandry specialists and other disciplines who have an understanding of those other parts of the system of which our equipment, even if vital, is only one part. It is this very complexity of agricultural processes and it is requirements of the equipment which makes our particular branch of the engineering profession one of not only great challenge but of satisfaction and one which should demand a status high among the engineering specialisms.

Let us then turn to the future in which questions abound. Will and should technologies continue to advance with enough food and surpluses in many countries? If so, at what rate? What will be the priorities of the engineer in agriculture and horticulture? Should we continue to see this area as a specialism? What should the Institution of Agricultural Engineers set out to do? Will a nationally based organisation, even with strong overseas links and activities, still have relevance? On these questions I can only give my personal view together with my assurance that they are questions regularly being addressed in the Institution's Council and Committees and they will continue to feature in my thinking in the remaining months of my Presidency and after.

I have no doubt whatsoever that technology and development of equipment will continue probably at an accelerating rate. The current revolutions in biotechnology and in microelectronics will be fundamental to the next 50 years advance. Within this next period we shall surely see the agricultural enterprise managed largely by artificial intelligence through computer-based hardware. We shall probably see plants and animals monitored through the detection of electro-physiological signals which at the moment we can only know to exist in what are regarded as the fringe fields of science. We may well have factory farming in the sense that crops are grown in completely artificial environments and we shall certainly see much more production at the cellular level of both propagation and growth within fermenters and factory-type installations. Despite the surpluses, and perhaps because of them, competition on a national, international and particularly intercontinental basis will increase, and this is likely to be the main motivation for a further increase in the rate of development. Before leaving technology, may I just ask you to cast your mind back as far as possible and identify those devices or techniques we now consider practicable or even have in use which could not be contemplated during the period of your early memories.

These advances in technology are all likely to result in more intensification and hence larger areas of the countryside becoming available for uses other than agriculture and horticulture. Some will become forestry, some will be preserved for its amenity and landscape value — in no case, however, will it not demand some skilled attention to maintain its productivity or its attractiveness. Although we may wish to regard it as a natural environment we would not be happy with its reversion to an unkempt and scrubby appearance. We must make sure that those skills which we have learnt to control our farming environment to be productive of food are also employed to control our amenity environments to provide the attractiveness we desire. Thus we increasingly regard ourselves not as engineers for agriculture but as engineers for the rural industries and activities.

For a rather different reason I consider that we must also look from the land to the husbandry of food production and perhaps even amenity creation and preservation within water. It is clear to me that the mechanisation of fish farming still has a lot to learn from equipment and techniques used in the husbandry of fatstock and poultry. In feeding, control of the growth environment and handling, there are opportunities for parallel requirements. Beyond fish farming one cannot ignore the possibility of crops being grown on a sea bed or within lakes and rivers particularly if these specific crops are chosen through their ability to produce a chemical or to nurture an organism which is of high value in industry or medicine. We and our Institution must therefore embrace equipment for aquaculture in the widest sense.

Another border of our field of activity which must be considered is that of the "downstream" regions of food production. We readily accept our expertise and responsibility to cover the on-farm processes that relate to crops or animals. Nevertheless in many cases more of the value is added off the farm in processing, packaging and storage and transport costs. As it is clearly not correct for agricultural engineers to divorce themselves from husbandry experts in on-farm activities, so it cannot be correct to hand over entirely to another group of engineers or scientists the moment the product leaves the farm. Furthermore, it may well be that the health of agriculture and the minimisation of production costs is better served by, for example, packaging and even some primary processing such as cleaning or shredding of vegetables being carried out on the farm, or growing enterprise itself. With livestock it is obviously unrealistic to expect one group of experts to look after the handling and welfare of animals on the farm, and the second group to have to learn the same expertise to plan and design for their handling and welfare in the abattoir. Thus there is little doubt that we must regard this border line as a much more flexible one than hitherto. Some caution must be shown in dealing with the chemical engineers, physicists and biologists who already occupy the field of food process engineering and the design of processing equipment. I find in the USA as well as in this country a degree of uncertainty about the roles and associations in this area, but in the medium term it seems to me quite clear that off and on-farm activities are likely to increasingly merge. The technologies employed will call for a closer association and we must have some part of our profession and of our Institution to represent, promote and maintain the engineering technologies that are applied to crop and animal processing off the farm as well as on it. One closing comment to this topic is that the size profiles of the companies manufacturing agricultural and horticultural equipment and manufacturing food processing equipment, are very similar with, in each case, some hundreds of companies but a relatively small number of large ones.

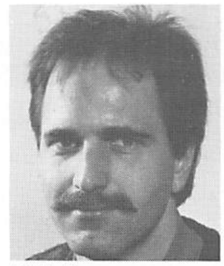
The final paragraph of my encouragement for the Institution of Agricultural Engineers to look outwards concerns engineering and scientific disciplines. Long past are the times when the Institution was a body of mechanical engineers brought together by the application of their engineering to agricultural and horticultural equipment. My own first degree was in physics and many other members of the Institution have primary qualifications outside mechanical engineering. In my view one of the principal justifications for our Institution is that it can bring together engineers and scientists whose co-operative participation can achieve more than their separate activities. I believe that we start our second half century needing to grasp the principal responsibility for information technology not only on the farm or in the horticultural business, but also in other rural and non-medical biological industries. I consider that in the same way that our first 50 years have been built around the mechanisation of effort, the next 50 years may well see as the major topic the mechanisation of intelligence or knowledge. We also need to raise the profile of process engineering within our Institution. This must go beyond the present specialisation of crop drying and storage, to the processing of tomorrow's products to meet the needs of biotechnology in single cell production and modification, novel extractions from plants, non-surgical embryo transplants, and perhaps even the micro-engineering of gene transfer. We need to be more positive in encouraging the membership of physical scientists in the Institution. They will contribute a great deal to the sensing and control which will be so much part of more precise production. At the other end of the equipment scale I am increasingly concerned about the relatively low proportion of design and production engineers which we have in the Institution. I would say to them that competition for their companies must mean the design and production of equipment of ever-increasing reliability and durability, which by definition requires, if it is to be achieved most economically, a greater understanding of the conditions within which their equipment will be used, of the operators and their requirements and habits, and of the extent to which their machinery or instruments will be seen as having the flexibility required within an industry which is in rapid change. The Institution can and must provide for the professional development of these engineers, if appropriate, in association with their production engineering institution.

Our Institution contains a high proportion of educators, trainers and advisers which is to the credit of the Institution as well as to the individual members. Despite the burgeoning growth within each of the sectors of artificial intelligence, mechanised communication systems and recipient controlled learning, the importance of their role will not surely be markedly reduced. Artificial intelligence is, after all, probably badly named as it is no more than stored intelligence. All of these aids based on the microelectronics revolution are essential in enabling us to keep up with the demands for knowledge. As with other service industries I consider the agricultural knowledge industry has a bright future. Its participants will be stretched as much as those of us in R & D by the acceleration in technological advance and by the demand for more detailed and more precise knowledge encompassing ever widening engineering and scientific sub-disicplines. This sector must surely also look to teach or advise across this broader horizon of peripheral activities, land and water based production together with food production and processing on and off the farm.

The opportunities for the Institution of Agricultural Engineers and for its members as it enters the second half of its first century, are therefore tremendous. Those of us in office already know that these opportunities are not easy to grasp and the routes for expansion of application or discipline need to be very carefully identified and given priorities if we are not to thrust out in all directions with little real success. Council know this but they do not have all the answers. My closing message to readers, particulatly to members of the Institution, therefore, is to encourage you within your branches or specialist groups to spend more time contemplating these opportunities and our best tactics. We need, throughout the Institution in the next year or two, to draw up strategies based on a consensus of view which takes into account the wisdom and experience of the whole membership.

The effect of lighting quality and intensity on the efficiency of seed potato inspection

D Zegers and V van den Berg



Didi Zegers

Valentijn van den Berg

Summary

MUCH of crop inspection work in farming and growing is performed under sheltered conditions, which implies that the physical environment can be controlled. A main environmental factor is lighting, as proper illumination is required to perceive details, colour and defects of root crops. To study this, experiments have been carried out with different degrees of lighting intensity (fluorescent lamps of three levels: 500, 1000 and 2000 lx) and of colour rendering index (two levels: < 85 Ra and 85 Ra).

The potato variety Bintje was chosen for a standard sample which consisted of 5000 "good" and 200 defective tubers (cleaned of haulm and dirt, size 28/35 mm). The defective fraction was composed as an "average" lot as occurring under practical farming conditions.

The inspection performance chosen, as a measure of the visual-perceptive and mental loads, is the proportion of defective tubers detected, assuming that the load is lower with a higher percentage of defective tubers present.

From the research results the following conclusions can be drawn:

(i) The lighting intensities of 500, 1000 and 2000 lux do not appear to effect significantly the inspection performance.

(ii) The choice of the fluorescent lamp type appears to effect significantly the inspection performance. Fluorescent lamps of a colour rendering index of 85 Ra resulted in a better inspection performance than those of a colour rendering index of < 85 Ra (77 Ra). Of the 85 Ra lamps the best performance is achieved when using a light colour (colour perception) of "normal" or "cool white".

1 Introduction

Agricultural products account for approximately 22.7% (value of 49.7 million guilders) of Netherland exports and contribute 5.1% to the national income. A product of good quality is a prerequisite for maintaining and strengthening this position. In agriculture, quality control has come to be a common activity, which is practised at many points in the production process. Questions that can be asked deal with control and inspection procedures, with costs, and whether the level of quality control can be raised, taking into account the availability and the workload on the persons involved.

The human factor in the agricultural inspection process has not received much attention so far; although a little research has been undertaken as to the substance of the job and the load on selectors (Carlow). The problem area is extensive (Megaw 1979, Harris 1969) but possible influencing factors can be discerned. Ergonomic research focuses on the selector. How does a person react to the (influencing) factors to which he is exposed? Can any signals be observed that reveal information as to how the person functions internally and externally? Collecting this information is complicated.

The multitude of influencing factors requires that the scope of research is limited to only a section of the total in order to prevent confusion. Of all factors in the inspection process the human one is likely to be the most difficult to assess. The other influencing factors tend to be technically adjustable within certain ranges, except for the nature of defects in the product. To explore a small section of the field, a start has been made with lighting. This factor was chosen because it can be easily manipulated in practice.

Many of the inspection processes on the farm are performed inside, where supplementary artificial lighting is used to create the required light intensity. In nearly all situations fluorescent tubes are used because of their low energy cost and high light performance. Fluorescent lamps are designed with several types of colour perceptions, ranging from "warm" via "standard" to "cool", to meet the special demands with regard to the subjective perception of the room in which they are installed.

In addition to the colour of the light, the lighting intensity at the work station is important for proper task performance. This paper examines the effects of the two factors of colour rendering index and lighting intensity on the inspection performance. The question is then formulated as: "is the inspection performance effected by the use of a certain fluorescent lamp type and/or by the lighting intensity?"

Didi Zegers is in the Work Study and Ergonomic Dept. and Valentijn van den Berg is in the Information and Statistics Dept of IMAG (Institute of Agricultural Engineering), Wageningen, Netherlands. *Refereed paper, submitted April 1987, accepted for publication January 1988.*

The choice of seed potatoes as test objects has been made because in the first place, the Netherlands occupy a leading position on the world market for seed potatoes and, secondly, tests can be easily carried out as IMAG has an experimental farm of its own ("Oostwaardhoeve" in Slootdorp) with experienced inspectors and sufficient quantities of potatoes available.

2 Theoretical Background

2.1 Quality control

In the 1970s interest in the performance of inspection was given impetus by the emerging Signal Detection Theory (Sheehan & Drury; 1971). In these years research was performed into the optimization of "quality control" especially for industrial applications. However, by the end of the seventies, this research came to an end. Nevertheless, quality control and supervision continue to occupy an important position within the production process. The development and application of micro-electronics have made it possible to have part of quality supervision carried out by equipment, especially in large-scale industrial organizations.

For the individual farm, investment in highly expensive inspection equipment is impracticable from the financial point of view, taking into account the short seasonal nature of operation. Hence, a large part of the inspection work is performed by hand, which may be aided by equipment. When the work is done manually, however, a potential source of error is introduced, so much research has been performed into possibilities of eliminating poor working conditions to present the objects to be inspected under the most favourable conditions with regard to speed, accessibility, etc.

These efforts have not resulted in completely faultless inspection. Under the best circumstances about 85% of defective tubers are removed. Unfortunately, it is not unusual for less than 50% of defective tubers to be removed. Therefore, it is sensible to extend the research to the inspector, the working conditions and the auxiliary equipment that is available.

2.2 Research model

Inspection and selection are activities in which 'man' occupies a central position and performs a duty under certain conditions. It would be helpful if all relevant influencing factors and their interactions were known, but this is not so. Various models have been produced of the selection task, ranging from simple to highly complicated ones (Sinclair, 1978).

This paper will describe a simple model of the selection task, which can be understood as a task in which tubers have to fall within a certain standard, or otherwise fail to do so. Generally, the checking will be visual, with the defective tubers being removed manually. In other words, the tasks involve processing information from external signals and translating this information into control over hand and arm movements.

The inspector's task can be conditioned by environmental factors, e.g. a certain (high) noise level can interfere with his or her concentration, insufficient or incorrect lighting will reduce the recognition of defects and thus render the task more difficult.

Except for environmental variables, the task performance is also effected by the equipment used (belt type, belt speed etc), the nature of tuber defects as well as their frequency. The selection process can be represented as comprising three groups of factors that reflect on the task performance: personal, task-related and environmental.

2.3 Personal factors

To determine the efforts made when performing the selection, the process of information, perception and processing is dealt with briefly. A first step can be made using the "SOR" model (Signal-Organism-Reaction) model which roughly indicates that a signal can activate a person to perform a certain operation. Information processing is rather complicated as it can be coded, transported, filtered, deformed, added to, compared with other information, channelled or obstructed. Mental load can be described as the load resulting from the processing of information. Mental load is natural, and in principle it occurs always. Information is continuously processed and if there is an ample supply, information perception will be lower. The perception and processing of information requires time, depending on factors such as efficiency of the control system and the possibility of processing the information simultaneously (in parallel) wholly or partly. The efficiency of the control system can change depending on a person's tiredness. Tired persons are assumed to be less attentive and, hence, less able to use time for the perception of (external) information and the subsequent processing of it.

Tiredness will lead to defective tubers passing unnoticed. Another aspect of mental load is that routine and experience develop, which facilitate the information control allowing the task to be performed more efficiently as it no longer requires a person's full attention.

It is not easy to measure the perceptive-mental load. Direct measuring on a person's body using the heart beat variability can only be done satisfactorily in controlled laboratory situations. In practical situations, therefore, derived parameters are relied upon, which are assumed to be reasonably reliable reflections of the actual mental load. A frequent measuring method is a behavioural study where, on the basis of errors made and the error pattern related to time, the actual load is estimated. Sinclair (1979) presents a good view of it.

The two most frequent parameters are:

(i) percentage of incorrect decisions (errors of the first and second type). The error of the first type is the fraction of defective tubers within the batch classified as "good", the error of the second type is the fraction of good objects in the batch classified as defective;

(ii) detection level: the percentage of defective objects detected.

2.4 Task factors

In the present research task factors refer to the equipment with which the work is done, the throughput of objects, speed of objects, the proportion and type of defects in the batch. An important item of this task is the detection of defective objects. The variety of defects in potato tubers can be very high, the most frequent ones are shown in fig. 1 and are listed below:

(a) deformity, growth cracks and scars, caused by combinations of varietal characteristics, soil structure and growing conditions (e.g. rapid growth in a previously dry crop after a wet period);

(b) damage and cracks, such as cuts caused during harvest;

(c) green tubers caused by exposure to light;

(d) Rhizoctonia, attacked by a soil fungus disease;

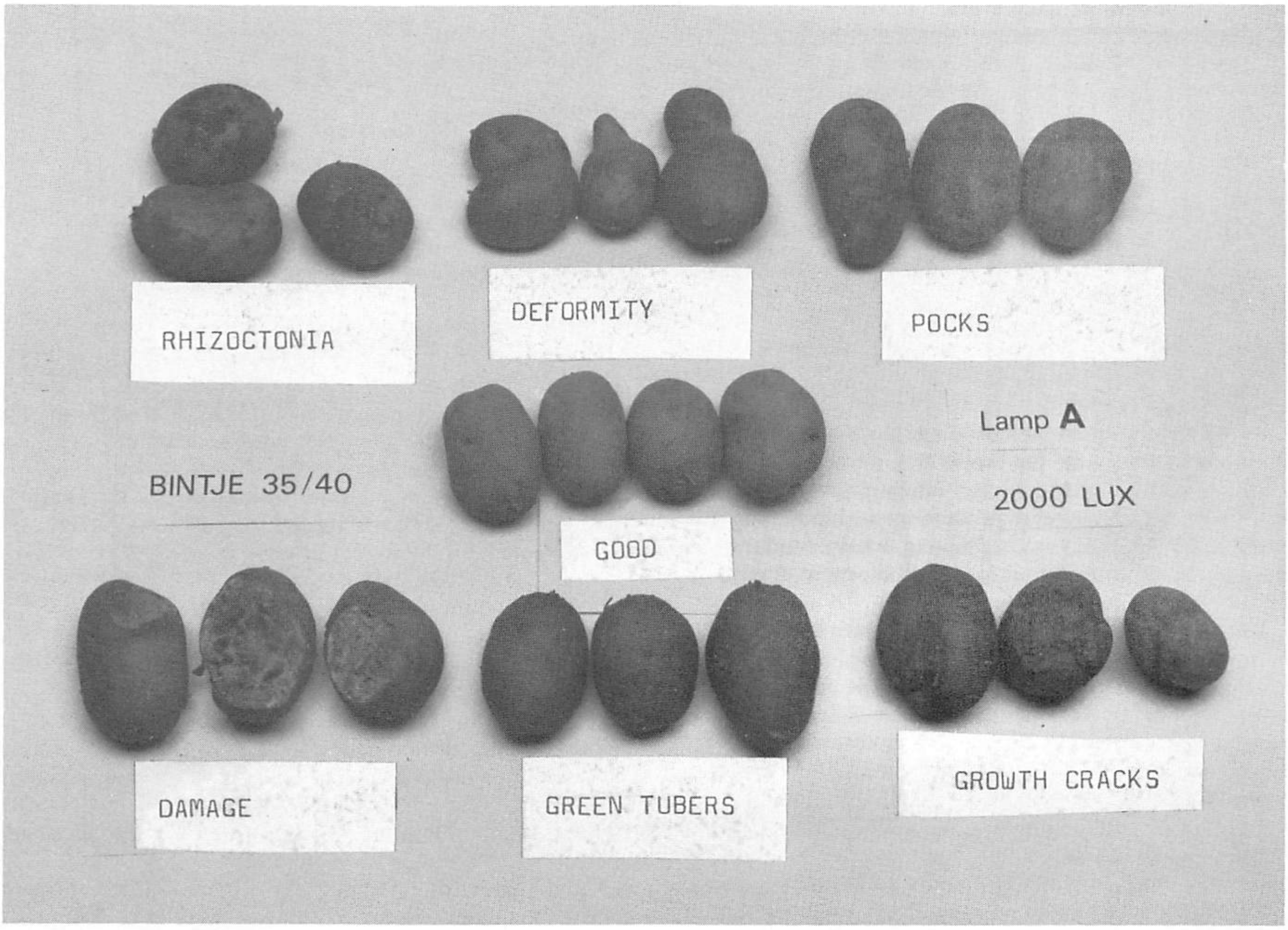


Fig 1 Examples of defects in potato tubers

(d) pocks and scabbiness, marks of a fungus disease which especially propagate when water is scarce during tuberisation.

Depending on the type of defect, there exist certain guidelines with regard to the proportion that can be tolerated in the batch, eg for Rhizoctania and scabbiness ranges are used that can be applied during inspection. Other defects are not allowed in principle to occur in the batch.

2.5 Environmental factors

The only environmental factor examined in this paper is illumination. The fluorescent lamp is a tube-shaped low-pressure mercury discharge lamp in which mainly short-wave UV radiation is generated; as such it is invisible, but it is partly converted into visible radiation through fluorescent powders on the inner tube wall. The combination of wave length and light colour generated by a fluorescent tube depends on the chemical composition of the powders used.

The common types of fluorescent lamp are based on two colour criteria, viz:

(a) colour rendering index-lamps can be arranged in classes,
(b) colour temperature, indicating the apparent colour of the light, distinguished in categories "warm", "standard" and "cool".

On the basis of data from literature, the nominal lighting intensity is 1000 lux (this means the lighting intensity that on average is present at the working station and on average over the maintenance period of the installation). In addition, the nature of the work requires the lighting to have the highest possible colour rendering index.

3 Test conditions

3.1 General

The research aimed at establishing the effects of a number of factors on the inspection performance, these factors being lamp type (light colour of fluorescent lamp), lighting intensity, time of the day when inspection was performed and the inspector under observation.

For testing, a standard seed potato sample was chosen (Bintje, cleaned of haulm and dirt, size 28/35 mm) with known numbers of good as well as defective tubers in it. The tubers, classified as defective, had been selected by an experienced inspector from a batch of rejected tubers, in consultation with the inspectors under observation in order to exclude any differences as to the classification of tubers. The total sample consisted of 5200 tubers, of which 5000 were good and 200 were defective. The composition had been based on the average of such material from the experimental farm over the last few years (though this composition did change considerably from one year to another). The defective tuber composition of the test batch was as follows:— Green 10%, pocks 10%, deformity 35%, Rhizoctonia 10%, damage 30%, growth cracks and scars 5%.

Seven types of fluorescent tube were used to illuminate the inspection table as given in table 1 and three lighting intensities of 500, 1000 and 2000 lux were employed.

Table 1 Fluorescent lamp types

Lamp notation	*Code*	*Colour temperature, °K*	*Colour rendering index, Ra*
A	WWX 183	3000	85
B	CWX 184	4000	85
C	DX 186	NR	85
D	UW	4000	76
F	D	6500	75
P	CW/IRS	4000	66
Q	D/RS	6500	75

NR - Not recorded

Three different but experienced potato inspectors were employed to carry out the inspection procedures.

To restrict the exchange and adjustment of lamps in order to keep experimental procedures within reasonable limits, it was decided not to pursue a fully randomised test. Instead the three inspectors were allocated at random for each adjustment of similar lamps.

Although inspectors conducted separate tests in both the morning and afternoon to assess the effect of part of day on tuber selection performance, it was also applied to measure replicate block effect. As a result few degrees of freedom were left for the corresponding residual variance, so that the part of the day effect cannot be estimated accurately.

3.2 Observations

The tubers were presented to the inspectors on a sorting conveyor. For each test the defective tubers were put back and intermixed over the entire batch as evenly as possible. The conveyor speed was such that all 5200 tubers had passed the inspector in approx. 10 min; which is the average speed in practical situations.

With each change of lamp type, inspector to be observed, lighting intensity and part of the day, the numbers of removed defective tubers per defect type were recorded; the total numbers of good tubers inadvertently removed as defective were only partly recorded and, therefore, have not been included in the analysis.

The variable of "inspection performance" (SR) is defined as follows:

$$SR = \frac{\text{number found of defect}}{\text{number present of defect}} \times 100\% \quad \text{.....(1)}$$

4 Statistical analysis

4.1 Introduction

As a result of the random mixing of defective tubers in the batch, which can be different between one test run and the next, the same inspector working under the same conditions of lamp type, lighting intensity and part of the day, will score different results. This will cause extra variability in the parameters to be analysed, as will the effect of tiredness for each inspector. However, this latter effect was not taken account of in the analysis.

4.2 Statistical model

In agricultural research it is often possible to verify the effects of the main parameters being tested and their interactions using the variance analysis technique. The conditions for this analysis are that defective tubers are distributed normally with a constant variable. The variable of "inspection performance (i)" analysed is a fraction that does not meet this supposition. The variance will depend on the value of the average: the closer SR(i) to 0 or 1, the smaller the variance.

It is customary in this type of situation to assume that the observations are distributed binomially with unknown fraction of defects found (P) and number of defects (N) (Williams 1982). In this type of case, a so-called Logit transformation is applied to the observations. The range of values, which for the original observations runs from 0 to 1, is the area of $-\infty$ to ∞ for the "logit variable". In this way a model is achieved that resembles the classic model, allowing the general variance analysis techniques to be applied.

The part of the day under which inspection took place (D) has been included in the mathematical model additively, which means that only the main effect of factor D is included, not the interactions with other factors. With treatments pertaining to the inspector observed (P) and lamp type (T) and lighting intensity (V) the main effects have been included. After transformation, the model is as follows:

$$\text{Logit SR (i)}_{jklm} = mu + D_j + P_k + T_l + V_m + PT_{kl} + PV_k + TV_{lm} + PTV_{klm} \quad \text{.....(2)}$$

where:
mu = general average
D = part of day (j = 1,2)
P = person observed (k = 1,2,3)
T = lamp type (1 = 1,2,....,7)
V = lighting intensity (m= 1,2,3).

Table 2 Degree of significance for the removal of terms from the model with all main effects for each type of defective tuber

Code model	*Removed term*	*Calculated F value for each significance level where p <: 0.05*	*0.01*	*0.001*	*Green-ing*	*Pocks*	*Defor-mity*	*Rhizoc-tonia*	*Damage*	*Growth cracks*	*Total*
j	V	3.1	4.8	7.3	-	-	-	-	-	*	-
k	T	2.2	3.0	4.0	***	***	*	-	***	*	***
l	P	3.1	4.8	7.3	***	***	*	***	-	*	***
m	T+V	2.0	2.7	3.6	***	***	-	-	**	**	***
n	P+V	2.5	3.5	5.0	***	***	-	***	-	***	***
p	P+T	2.0	2.7	3.6	***	***	**	***	***	**	***
q	P+T+V	1.8	2.5	3.2	***	***	*	***	**	**	***

* *Significantly different at p <0.05*
** *Significantly different at p <0.01*
*** *Significantly different at p <0.001*

The description above is for the complete model. Subseqently by systematically removing terms, the effect of the removed term can be statistically tested.

4.3 Summary of analyses performed

The various effects were analysed with an F test, always performed comparing with the model with the main effects of D, P, T and V without interactions. From the figures 2, 3 and 4 and the calculated values for the F tests, table 2 was composed.

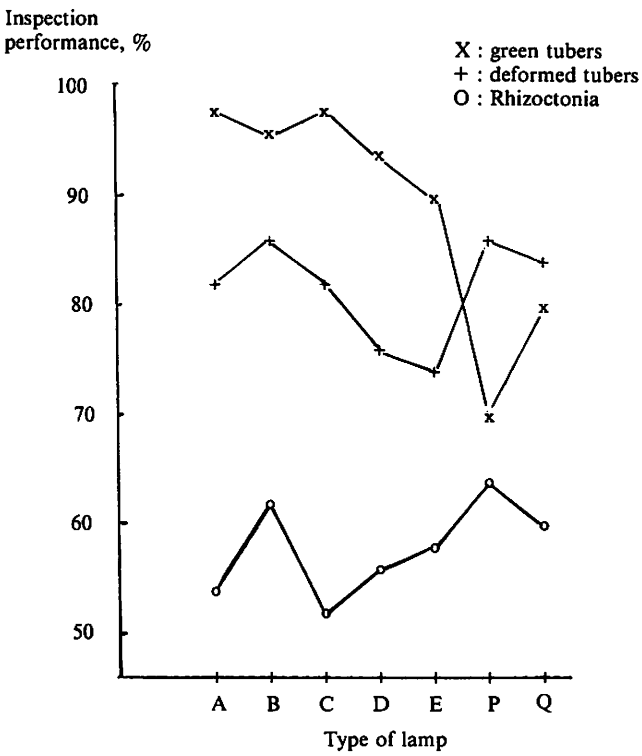
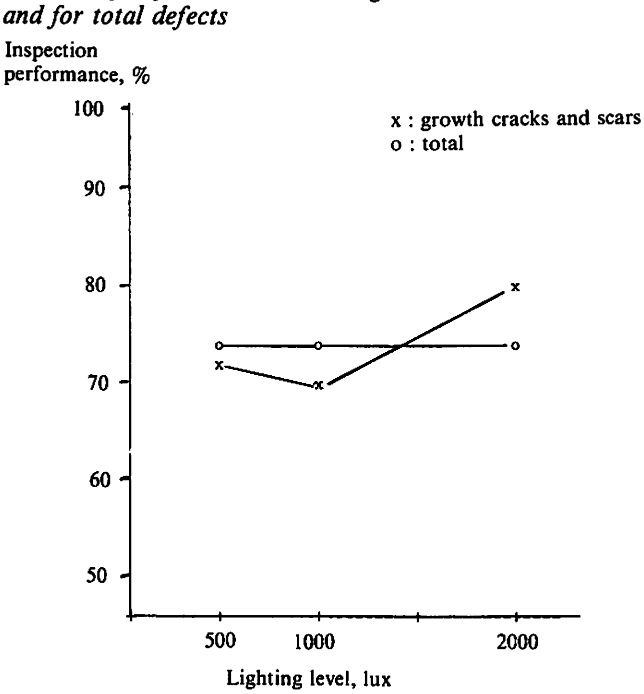


Fig 2 Inspection performance from each type of lamp for removal of defective tubers with greening, deformity and Rhizoctonia

Fig 3 Inspection performance from each lighting level for removal of defective tubers with growth cracks and scars and for total defects



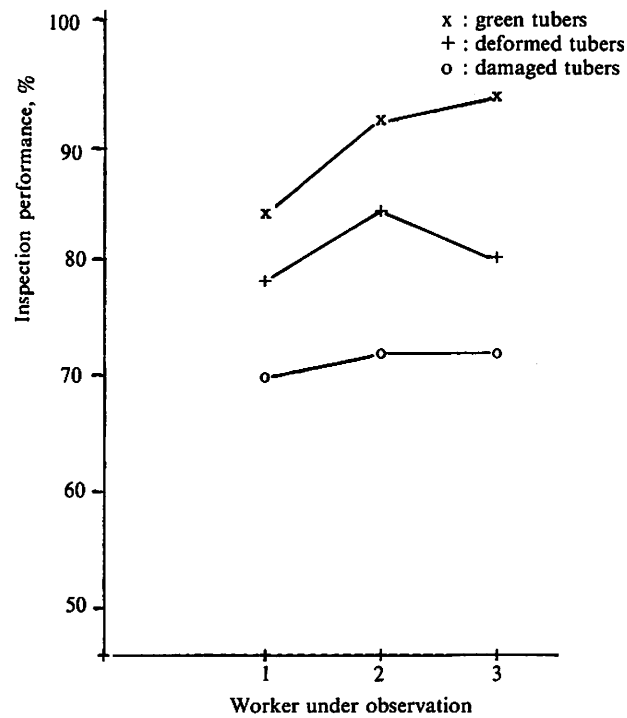


Fig 4 Performance for each inspector observed when removing defective tubers with greening, deformity and damage

4.4 Results of analysis

4.4.1 General

Considerable differences were observed for the individual types of defective tuber, the scores for green tubers and deformity were relatively high and for pocks and Rhizoctonia low, as shown in table 3.

Table 3 Inspection performances for each type of tuber defect

Defect	*Average, %*
Green tubers	89.5
Pocks	62.1
Deformity	80.9
Rhizoctonia	58.1
Damage	70.4
Growth cracks and scars	73.4
Total	74.1

4.4.2 Fluorescent lamp type (T)

For defects due to green tubers, pocks, damage and for the total, the type of lamp significantly effected ($p < 0.001$) the inspection performance; with deformities and growth cracks giving similar results at lower significance levels ($0.01 < p < 0.05$); with Rhizoctonia no significant differences occurred. The results given in fig 2 and table 4 indicate that the use of lamp types A, B and C resulted higher than average scores. Lower scores for detecting Rhizoctonia resulted from the use of lamps A, C, D and also for detecting growth cracks from using lamps B, C, P, Q.

4.4.3 Lighting intensity (V)

As shown in fig 3 and table 5, the inspection performance was significantly reduced ($0.01 < p < 0.05$) when lighting intensity was reduced for growth cracks and scars. However, lighting intensity had no significant effect on inspectors selecting and removing other defective types of tubers.

Table 4 **Relative inspection performances for each lamp type (plus = better than average, minus = worse than average)**

Lamp type	*Green*	*Pocks*	*Deformity*	*Tuber defect Rhizoctonia*	*Damage*	*Growth cracks*	*Total*
A	+	+	+	-	+	+	+
B	+	+	+	+	+	-	+
C	+	+	+	-	+	-	+
D	+	+	-	-	-	+	-
F	+/-	+	-	+/-	-	+	-
P	-	-	+	+	-	-	-
Q	-	-	+	+	-	-	-

Table 5 **Inspection performance for growth cracks and scars and the total from three lighting intensities**

Lighting intensity, lux	*Inspection performance, % Growth cracks*	*Total*
500	71.2	73.0
1000	69.3	74.5
2000	79.8	74.8

4.4.4 Inspector (P)

With defects due to green tubers, pocks, Rhizoctonia and for total defects the inspectors performance were significantly effected ($p < 0.001$); deformities, growth cracks and scars had a somewhat similar but lower significant effect ($0.01 < p < 0.05$); there was no significant effect on inspectors' performance from damaged tubers. Detailed results are given in fig 4 and table 6. These show that inspector 1 scored systematically lower than the other two.

4.4.5 Time of the day (D)

The effect of the part of the day on the inspection performance is given in table 7. For defects, due to growth cracks and scars and for total defects, the afternoon performance of inspectors was significantly greater ($p < 0.05$) than in the morning. However, it is considered that the test gave too high a level of significance because of the model used as stated in paragraph 4.2 "the statistical model".

5 Discussion

The research results allow the following conclusions to be drawn:

The inspection performance averaged 74% (table 3), which could be considered "fair" compared with average results in practice which range between 50 and 80%. It was surprising that the performance in the afternoons tended to be better than in the mornings.

The lighting intensity did not show a significant influence on the inspection performance except for growth cracks and scars (table 5). In the range of 500–100–2000 lux the lighting intensity did not significantly affect the performance, which contrasted with recommendations giving at least 1000 lux as a standard. This might be explained by the accommodation of the inspector's eyes to the various lighting intensities.

The type of fluorescent lamp used effected the inspection performance significantly (table 4). It was in agreement with the usual assumption that performance was better when the fluorescent lamp had a high colour rendering index. Hence, inspecting with fluorescent lamps of 85 Ra will give better results than those of an index of less than this.

In addition to lamp type, different inspectors had a strong effect on the inspection performance, therefore the persons involved in the experiments were asked for their opinions of the lighting levels and of the types of fluorescent lamps used. Their opinions are summarised below:

(a) all inspectors found the lighting level of 500 lux too dark, though no reduced performance was observed for reasons stated previously.

(b) The levels of 1000 and 2000 lux were variously described as being "too dark" or "glaring". However, the following generalisation was made: lamps of a colour rendering index of less than 77 were only found "good" at 2000 lux; lamps of 85 Ra were found to be "good" at a level of 1000 lux,

Table 6 **Inspection performance (%) worker under observation**

Worker observed	*Green*	*Pocks*	*Deformity*	*Tuber defect Rhizoctonia*	*Damage*	*Growth cracks*	*Total*
1	83.2	51.9	77.9	54.8	67.2	67.4	68.0
2	91.4	69.9	84.8	59.8	71.7	76.9	78.1
3	93.8	64.5	80.2	59.6	72.5	76.0	76.1

Table 7 **Average inspection performance (%) for each part of the day**

Part of day	*Green*	*Pocks*	*Deformity*	*Tuber defect Rhizoctonia*	*Damage*	*Growth cracks*	*Total*
morning	88.6	60.0	81.0	55.6	68.8	70.2	72.9
afternoon	90.3	64.2	80.9	60.5	72.1	76.7*	75.3*

**significanly greater ($p > 0.05$)* than the morning score.

and 2000 lux lamps of "normal white" and "cool white" were sometimes found "glaring".

The experiments were carried out with potato variety Bintje and similar results with other varieties might occur, provided these have a similar (yellow) skin. Even use of red-skinned varieties might result in a similar performance being obtained, because yellow and red are at the same end of the spectrum.

6 Further work

In these experiments no consistent replications were applied for the time of day being used. Therefore, further experiments are required to evaluate this aspect.

During the experiments, only comparatively short working periods were undertaken at any one setting of the parameters being investigated. Thus further long term trials shoud be carried out, especially with lamps of the highest colour rendering index.

In addition, it might be useful to select lighting intensities at intermediate intervals since the optimum value of the inspection performance might prove to be somewhere between the values used.

References

Harris D H (1969). The nature of industrial inspection. *Human Factors,* 11, 2, 139–148.

Lion J S, Richardson E, Browne R F (1969). A study of the performance of industrial inspectors under kinds of lighting. *Ergonomics*, 11,1, 23–34.

Megaw F N (1979). Factors affecting visual inspection accuracy. *Applied Ergonomics,* 10, 1, 27-32.

Nelder J A, McCullagh P (1983). Generalized linear models. Chapman and Hall, London.

Sheehan J J, Drury C C (1971). The analysis of industrial inspection. *Applied Ergonomics,* 2, 82, 74–78.

Sinclair M A (1978). A collection of modelling approaches for visual inspection in industry. *Int J Prod Res,* 16, 4, 275–299.

Sinclair M A (1979). The use of performance measures on individual examiners in inspection schemes. *Applied Ergonomics,* 10, 1, 17–25.

Williams D A (1982). Extra-binomial variation in logistic linear models. *Applied Statistics,* 31, 2, 144–148.

Tractor efficiency and fuel conservation — a New Zealand approach to farm advisory work

R E H Sims, R W J Young and G A Martin

Summary

A TRACTOR economy programme, "Tractor Facts", was recently developed by a group of New Zealand agricultural engineers in an attempt to disseminate useful information on tractor selection and operating efficiency to as many users as possible. The approach used could have value in other countries attempting to improve tractor operation through education and demonstration.

Initially a series of field days was held to demonstrate the principles involved in maximising drawbar power, measuring wheel slip, selecting gears etc. Equipment used for this work was owned by local farmers. As well as fuel conservation, emphasis was placed on saving time, cutting machinery costs and reducing damage to the soil. Farmers were invited to bring along their own tractors to be tested for power output, weight and checked for tyre conditions. Recommendations on ballast, tyre pressures etc were then given on the basis of operating speeds and work done.

Similar but more detailed sessions were also organised for tractor dealers to enable them to provide a more informed service to their customers.

Farmers who had attended the field days were surveyed several months later to ascertain how much of the theory learned they had put into practice and what benefits they had gained. The results were encouraging but a number of barriers to satisfactory implementation were also identified.

The overall response from this programme gave confidence to promote a professional package aimed at: (a) those factors which can be controlled by the tractor operator when in the field and (b) those factors which govern the decision to buy a specific size, type and model of tractor. The "Tractor Facts Pack" was released in May 1986 and promotion of the programme is continuing.

The unique annual National Tractor Pulling Competition is also discussed. It is a true test of the drivers' skills in maximising the tractive efficiency of their unmodified tractors when working in field conditions. It is therefore of educational value to farmers who wish to optimise their tractor efficiency.

Ralph Sims is a Senior Lecturer, Agricultural and Horticultural Machinery, Massey University, Palmerston North, New Zealand.

Roger Young is Senior Research Officer, New Zealand Agricultural Engineering Institute, Lincoln College, Canterbury, New Zealand.

Graeme Martin is Senior Engineer with the Ministry of Agriculture and Fisheries, Christchurch, New Zealand.

1 Introduction

In 1983 a project was commissioned by New Zealand's Energy Research and Development Committee (NZERDC) to provide an overall picture of energy supplies and conservation on the farm (Sims *et al* 1983).

One of the major recommendations was the need for improvements to tractor and implement performance. A promotional programme was recommended involving farmer field days, demonstrations and distribution of advisory leaflets. To be successful it was aimed at tractor dealers as well as owners and drivers. The objective was to provide farmers with a means of reducing their costs (including fuel) by operating their tractors and machinery at maximum efficiency. This necessitated giving them a thorough understanding of tractor selection, operating techniques, and maintenance procedures.

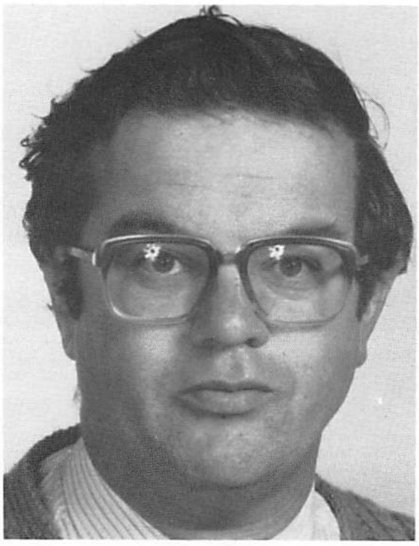
The prospective adverse economic climate for the farming industry meant that the critical timing of the campaign required the planning to begin immediately if it were to prove successful and cost effective. This was duly done, and following extensive pilot studies, the programme was launched in May 1986.

This paper describes the progress made in providing farmers with the necessary information to reduce their machinery costs and fuel use. Monitoring their response in terms of improved efficiency in the field is discussed. It also attempts to show that a similar approach may have benefits in other countries.

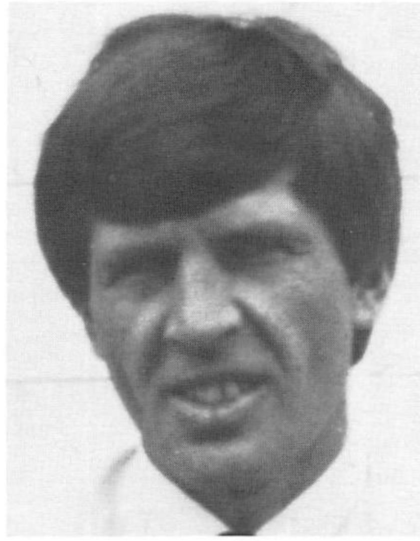
2 Procedures

2.1 Phase I — Field days

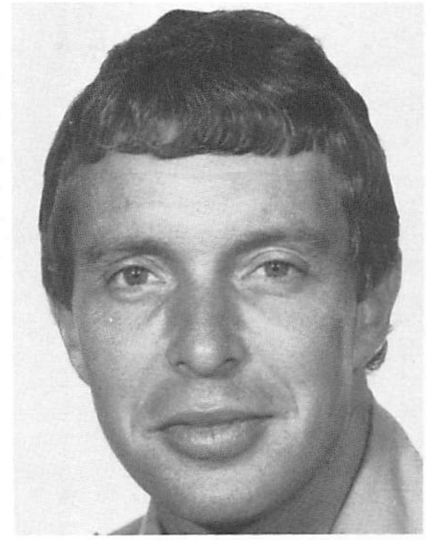
First, in order to assess the potential benefits from producing a practical and technical information package for tractor operators, a series of one-day field days was organised during 1985 in the main arable areas of New Zealand. The NZ Agricultural Engineering Institute (NZAEI) developed novel equipment to help demonstrate efficient tractor operating techniques in the field situation. The Ministry of Agriculture and Fisheries provided agricultural engineering staff to assist with the presentation and the programme was funded by both the



Roger Young



Graeme Martin



Ralph Sims

NZERDC and the Ministry of Energy who were interested in the possible fuel savings. However, it was realised from the start that farmers would have very little interest in saving fuel *per se* (since it is a relatively small proportion of total farm costs) unless it was associated with savings in time and improvements in overall efficiency (Sims *et al* 1983).

Groups of no more than 30 farmers were invited to attend each of the field days and to bring along their tractors for evaluation. A small technical booklet was produced and given to each of those present summarising the main points. A very small charge was made for enrolment.

2.1.1 Demonstrations

The day began with a short series of simple questions on wheel slip, power units etc. Many present found those questions difficult and hence realised how little they knew. Small groups were rotated in turn around three simultaneous demonstrations in the field spending 45 minutes at each. These were as follows:

(i) Engine speed/gear selection and instrumentation (e.g. fuel flow meters). A specially set up tractor was used for this.

(ii) Hydraulic operation, mounted and trailed implements and measurement of wheel slip. A local tractor was borrowed for this demonstration and used to pull a modified cultivator that could be used either trailed or fully mounted. A monitor to record working depth was added so that constant depth could be maintained in order to obtain worthwhile comparisons of wheel slip measurements.

(iii) Drawbar power and pull in association with 2 and 4 wheel drive, tyre equipment and tractor weight addition. For this demonstration a one-fifth scale electric powered model tractor was designed by staff of the NZAEI and operated in a portable soil bin or directly on the ground (fig 1). It proved invaluable in demonstrating many technical points within the short period available and proved to be one of the most successful methods of getting information across to the farmers.

2.1.2 Field measurements

Prior to each field day, three local drivers were each asked to operate their tractor and implement in the field as they would normally. Fuel meters were first installed so that fuel consumptions and work rates (ha/h) could be recorded while the methods of operation (e.g. use of draft or position control) were observed. The results were presented at the field day.

Fig 1 The model tractor used to demonstrate effects of front and rear ballast, 2 or 4 wheel drive, duals versus singles, drawbar power, wheel slip, hitch height and and tyre pressures

The group were then asked how each of these three tractors could be operated more efficiently taking into account what they had just learnt. Any suggestions made (such as removing water ballast from the front tyres) were evaluated by operating the appropriate tractor after suitable adjustments had been made. The effects were measured and often significant improvements were obtained which served to convince the farmers of the value of the information. For example, a 90 kW, 4-wheel drive tractor working with a 4 m wide cultivator initially had wheel slip of 15%, fuel consumption of 11 l/h and a work rate of 2 ha/h. By reducing the implement working width to 3 m, (by removing some of the tines), wheel slip was lowered to a more acceptable 7%. This gave a faster forward speed and work rate (2.45 ha/h) and also reduced the fuel consumption to 7.5 l/h.

Over-weighting was shown to be a common cause of inefficiency. For example, a 52 kW 2-wheel drive tractor pulling a cultivator produced only 6% wheel slip, implying it was too heavy. Almost a tonne of ballast weight was removed which increased wheel slip to 9%. As a result, in the same gear and engine speed, fuel consumption was reduced by 16%. The reduced effects on soil compaction were also emphasised.

Another example was simply to remove the depth wheels on a farmer's subsoiler and to use the draft hydraulic control system correctly instead. This improved fuel consumption by 14%, however, as a consequence, the driver was able to change up a gear, reduce engine speed and save even more fuel.

The benefit of "gear up — throttle back" was also demonstrated convincingly by a 46 kW tractor pulling a 3 m wide cultivator at 9.4 km/h with a fuel consumption of 2.6 l/ha. The farmer had operated the tractor the previous day in 5th gear at 2400 rpm but, by changing up to 6th gear and reducing engine speed to 1650 rpm, 15% less fuel was used, the engine was not overworked, the work rate was maintained as was the tilled effect on the soil. In fact, the implement was too small for the tractor since operating in 7th gear at 1200 rpm at a forward speed of 12 km/h was a possible combination as well. In this instance fuel consumption was similar to that obtained initially (2.5 l/ha) but the workrate had increased by 30%.

Many similar examples were recorded but more noteworthy was their demonstration at the field days in front of an audience using their own local tractors. This made greater impact than operating specially set up machines to demonstrate a point.

No criticism of the volunteer tractor operators was intended. Indeed there were a few occasions when no improvement could be made since initially the tractor was being operated efficiently. Such cases served to demonstrate the points that should be considered to maximise efficiency and save costs.

2.1.3 Tractor clinic

The final part of each field day consisted of checking tractors that had been brought along and giving advice to the owners and/or operators.

Tyre pressures were measured, the variations between wheels, at times, proving embarrassing for the driver! Power testing on a calibrated dynamometer generally gave satisfactory results though 18% of those tested were more than 10% below the test report figure. This was not necessarily noticeable to the operators when working in the field but it could reduce their overall work rates.

Occasionally a tractor was more than 20% down on power which could make it more costly to operate for certain jobs. Usually engine maintenance work could return it to an acceptable performance level and this was discussed with the owner.

Weighing each tractor provided useful information for the operators, particularly in one case where almost 5 tonnes of unnecessary ballast weight had been added to a 150 kW, 4-wheel drive tractor.

Large variations in net tractor weight were noted for the same size tractors. For example, three different makes of unballasted 60 kW models weighed from 1.7 to 3.7 tonnes, which effected the recommended weight addition to a significant degree in each case.

These informal individual discussions at the end of the event were the highlight of a worthwhile day for many of those present.

2.2 Phase II — Survey

It was impractical to reach all the drivers of the 80,000 tractors in New Zealand by holding field days for only 30 at a time. However, before spending considerable time, effort and money on a wider-reaching campaign it was deemed important to ascertain whether the field days had in fact proved to be worthwhile. The Market Research Centre, Massey University was consulted and a survey of those who had attended was conducted six months after the field days to see what changes had been made. The major results were as follows:

(a) 98% rated the field day as being worthwhile;
(b) 55% had changed the tractor's weight since the event;
(c) 46% had started to use the "change up-throttle back" technique;
(d) 16% had altered the method of implement operation;
(e) 32% had adjusted the implement operation;
(e) Only 12% had measured wheel slip;
(g) 39% had achieved lower fuel consumption whilst another 26% had expected savings but been unable to quantify them;
(h) Only 12% kept fuel records;
(i) 92% recommended to their farming friends attendance at such field days.

This overall satisfactory response was enough encouragement for the major phase of the programme to be undertaken. It also highlighted important areas, such as wheel slip measurement, that required greater emphasis.

2.2.1 Tractor dealer seminars

For the programme to produce maximum national benefits, it was considered important that tractor dealers should be provided with a similar level of knowledge to that being given to their farmer customers. In addition, it was realised that dealers have a major influence on a driver's attitude to selection and operation of his tractor.

Consequently two-day dealer seminars were offered individually to all national major tractor dealership networks in New Zealand, several of whom took the opportunity to accept. The seminars were based on the farmer field days but used only current models of tractor sold by a dealer, eg for a Ford dealer's seminar only Ford tractors were used.

In addition, time was spent on such subjects as: correct operation of a dynamometer, the need for 2 or 4-wheel drive (bearing in mind the extra profit margin from selling 4-wheel drives), the practical value of using tractor test reports, etc. Since dealers holding the same franchise from all over the country were gathered together, the importing company/manufacturer often took the opportunity to include aspects of sales promotion, and details of new models during the meeting. Each company was charged for the seminar on a commercial basis.

Dealers holding other franchises who had not accepted the offer to run a seminar, often expressed disappointment and also resentment at not being invited to one of the farmer field days in their area. It was however considered essential that the results from the demonstrations were seen by the farmers to be independent of the make of tractor being operated. Use of the results to compare tractors or generate sales would have caused confusion and greatly reduce the value of the field days.

2.2.2 Farmer organisations

The concept of the proposed tractor efficiency campaign was discussed at annual conferences of such diverse groups as the NZ Agricultural Contractors' Federation, the NZ Vegetable Producers' Association and the Sports Turf Institution. An enthusiastic response to the idea was obtained in each case. This gave further encouragement to proceed and added confidence to approach the Ministry of Energy to be the principal funding agency and to be co-ordinator of Phase III of the programme.

2.3 Phase III — "Tractor Facts Pack"

A professional promotional company, was commissioned to process a technical information package into an acceptable format and to market it. Basically the package consisted of a video, wheel slip calculator, field pocket-book and manual.

2.3.1 The video

Initially, it was intended to produce two 15 minute videos, one aimed at the tractor driver and the second involving tractor selection. In the event the latter was thought to have less impact so only one was produced with a running time of 21 minutes. It included: the use of hydraulics, how to measure wheel slip and use the results, engine speed/gear ratios, the need for correct tyre pressures and keeping fuel consumption records. A New Zealand farmer (rather than an actor or expert), who had actually benefited from attending an earlier field day, was chosen to present the video in an informal style with most shots being taken around tractors working in the field. The video received the "Best Training Video of the Year Award" from the New Zealand branch of the International Television Association and then was awarded the Silver Medal at their international competition held in Washington D.C.

2.3.2 Field pocket-book and wheel slip calculator

These were kept with the tractor to give an immediate reference for the driver when working in the field. The subject material was closely related to that contained in the video and was given in a clear, easily read form without detailed explanations.

The calculator enabled wheel slip to be calculated simply and with minimum arithmetic. In addition, it gave guidance for tyre inflation pressures and maximum loads carried.

2.3.3 Manual

This described and explained all the basic elements of efficient tractor operation gathered from research findings around the world. Ideally the tractor driver should read it first. It explained how efficient tractor operation had three main aspects, viz.

(a) correct matching of tractor and implements;
(b) proper setting-up and adjustment;
(c) good driving techniques.

It consisted of two main sections:

(1) Principles of efficient tractor operation:
  - tractive efficiency and wheel slip,
  - procedure for adding weight,
  - hydraulics,
  - engine speed/power output,
  - fuel efficiency,
  - p.t.o. operations,
  - maintenance,
  - dynamometer testing,
  - turbochargers,
  - tyres,
  - record keeping.

(2) Tractor selection:
  - tractor and implement sizing and matching,
  - p.t.o. power ratings,
  - torque rise,
  - fuel consumption,
  - transmissions,
  - hydraulic controls,
  - 2 or 4-wheel drive,
  - basic weight,
  - instrumentation,
  - ergonomics.

The use of tractor test reports was included in the appendix of the manual.

The text included a series of actual case histories where putting theory into practice had achieved significant advantages (Martin *et al* 1986).

2.3.4 Marketing the package

In order to achieve a significant impact with resulting benefits to the agricultural community a major promotional effort is currently underway. Field advisory officers (agricultural engineering) from the Ministry of Agriculture have undergone a training and refresher course and several are involved within their districts in organising future field days in response to farmer and grower demands.

The package is being promoted at agricultural shows and events throughout the country. Case histories are being published in the farming press and it is hoped to show the video on a weekly television agricultural programme. Interest in using the package has been generated overseas and such organisations as training boards, agricultural colleges, and tractor manufacturers are keen to utilise the material. The award of several prestigious Blue Ribbons by the American Society of Agricultural Engineers' Committee on Extension has served to enhance this interest.

Future events are planned, ranging from a simple one hour lecture (including showing of the video and answering questions) to a full two-day session covering a wider range of demonstrations, in-field comparisons etc. The former would involve only a knowledgeable presenter whereas the latter would require three specialists, three technical support staff and take 40 man-hours of on-site preparation. A wide range of options are offered between these two to suit the demand. A nominal charge will be made as it is considered that more notice is taken of

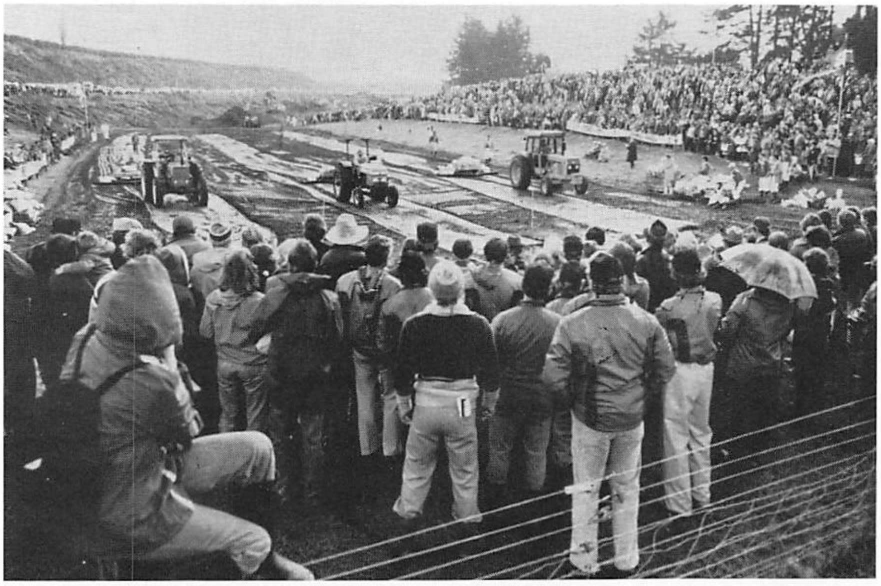


Fig 2 Rain did not deter the large crowd gathered to watch the annual New Zealand tractor pulling competition

information if the customer has to pay for it.

In addition, demonstration farms are to be monitored to show the benefits that can be achieved over time with an emphasis on reducing waste rather than on the savings that can be made. Organisations employing several tractor operators will be targeted for special training sessions.

3 Tractor pulling competition

It is appropriate to mention the national tractor pulling competition (fig 2) which has been held annually at the New Zealand National Agricultural "Fieldays"* Event for 14 years (Sims and Barr 1982, Sims 1981).

Unlike other tractor pulling competitions around the world, it is restricted to conventional unmodified agricultural tractors. It is basically a test of the driver's operating skills in maximising drawbar power and therefore closely simulates what should happen in practice. Hence it has an important educational value for both competitors and spectators but is also an enjoyable event in which to participate and to watch. Many competitors with their tractors travel hundreds of miles to the event, year after year.

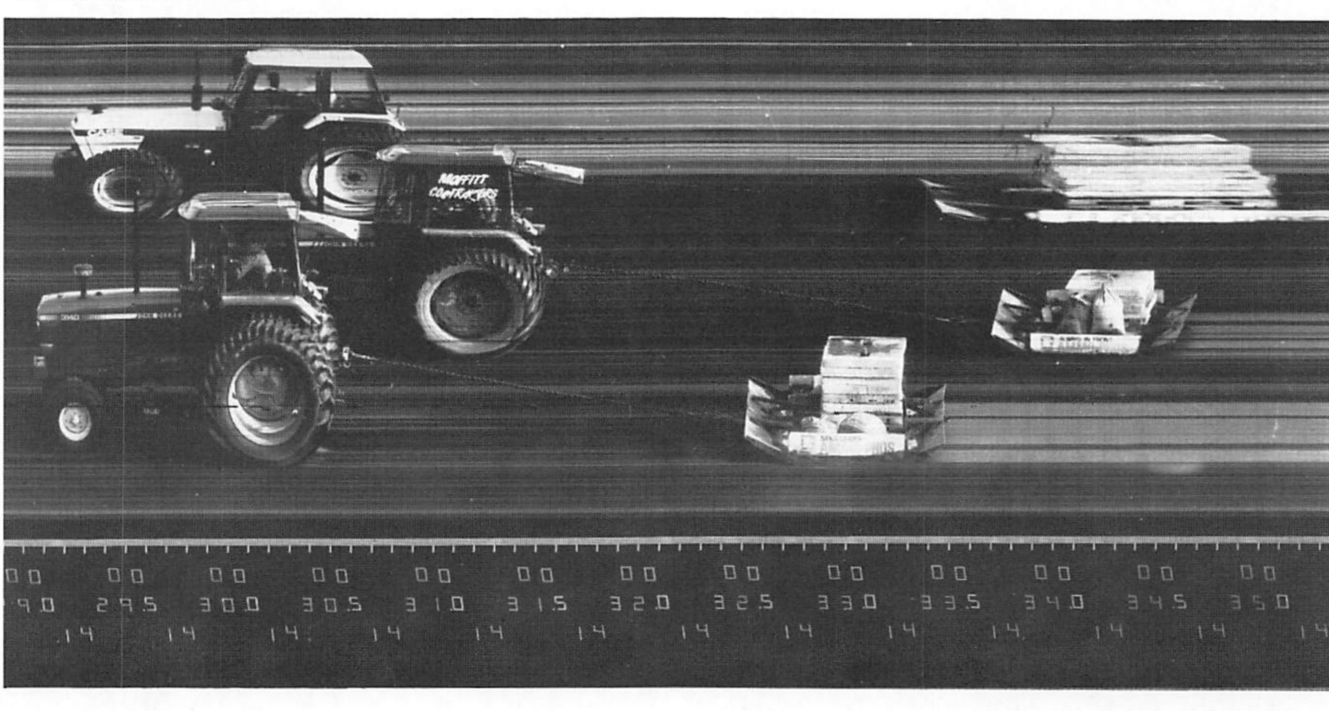
Each tractor has to pull a weighted steel sledge over a 100 m cultivated course as rapidly as possible. The sledges are carefully calibrated and weights are added to them in proportion to the engine power of the tractor to the nearest 10 kg. Thus, any tractor regardless of size, has an equal chance of winning the prize money.

The driver can select tyres, pressures, hitch height, gears, engine speed, hydraulics and weight added, that he considers will convert as much of the engine power as possible into useful drawbar pull according to the soil conditions. The eliminating heats consist of three competitors racing together over the course and being timed individually using a photo-finish camera (fig 3).

The nine fastest entrants from the heats then compete in a knock-out competition consisting of three semi-finals, a mini-final and a grand final to determine the first six places. The event is quite exciting and has considerable spectator appeal.

Entries range from 20 kW to 150 kW tractors and include both 2 and 4-wheel drives. Interestingly a 4-wheel drive has only won twice in the seven years the competition has been run in its current format. This stimulates considerable debate, but

Fig 3 A photo finish enabled the winner of this heat to be determined, there being 0.19 seconds difference in time after racing over the 100 m course



THE AGRICULTURAL ENGINEER

Subject Index & Author Index

1987

The Agricultural Engineer

Subject Index 1987

Title of paper	*Author*	*Yr of publ*	*Vol no*	*Pt no*	*Page*
Advances in machine technology	Godwin R J	1987	42	3	66
Developments in machinery and techniques for improved soil and water management	Spoor G	1987	42	3	67–72
Spray application technology	Miller P C H	1987	42	3	77–84
Rotary implement (the 'Sturplow')	MacIntyre D Sharp M J and Gray A G	1987	42	4	120–123
Research and development facilities in Europe	Duncan I J	1987	42	4	117–119
Marketing research: has it a role in applied research and development?	Knox S D	1987	42	4	107–112

Education and careers

A new facility for agricultural engineering education and machine test and development work	Hemingway P F	1987	42	1	32
The Engineering Council — five years of progress	Levy J C	1987	42	2	61–63

Electricity and electrification

A battery powered skid-steer loader	Alcock R	1987	42	1	4–8

Energy

Developments in solar grain drying in Scotland	Spencer H B and Graham R	1987	42	1	24–29
Water hyacinth and soil fertility	Casebow A	1987	42	2	36–44

Environmental control

The environmental requirements of livestock	Bruce J M	1987	42	4	137–140

Fertiliser, manure distribution and handling: farm waste

Water hyacinth and soil fertility	Casebow A	1987	42	2	36–44

Grain harvesting

Combines and straw	Nation H J	1987	42	1	2–3
A new stripping header for combine harvesters	Klinner W E, Neale M A and Arnold R E	1987	42	1	9–14
A cost model of straw conservation systems	Clegg J M and Noble D H	1987	42	1	15–20
The combine business	Williamson J A	1987	42	1	21–22
The Laverda transverse rotary combine concept	Bosworth P	1987	42	1	23
Innovations in harvesting technology	Klinner W E	1987	42	3	85–91

Hay and forage harvesting, handling and storage

Innovations in harvesting technology	Klinner W E	1987	42	3	85–91

Hydraulics

Tractor hydraulics and implement control	Bellanger R	1987	42	3	73–76

Livestock production and care

The environmental requirements of livestock	Bruce J M	1987	42	4	137–140

The Agricultural Engineer

Author Index 1987

on the flat course and on the frictional pumice soil, this is not so surprising as might first be thought. With large sums of money to be won, drivers use every conceivable trick to give them an advantage of only the fractional second sometimes needed to win, (eg reversing the tyres on the drive wheels, using dual wheels, fitting flotation front tyres to reduce rolling resistance and connecting pressure control hydraulic hitches).

However the rules strictly prevent modifications to fuel systems, governor settings, unspecified turbo-charging and if the front wheels leave the ground, the competitor is disqualified. Each tractor is power tested on a dynamometer to ensure it is within the manufacturer's specifications and "dope-tests" are conducted after the race. An additional benefit of the competition has been the monitoring of the performance of new tractors. For instance, one new tractor was found to be well underpowered and eventually the serviceman ascertained the cam shaft timing mark had been set wrongly at the factory. Another brand new machine was shown to have been delivered producing 500 rev/min above manufacturer's maximum specified limit. Yet another competitor entered his tractor at 87 kW but only 65 kW could be obtained by the pto dynamometer; eventually it was ascertained he had been supplied with the wrong model. All of these examples were genuine mistakes but without such checks the operators had no means of knowing.

The competition stimulates thought and discussion within the tractor-driving population and this interest is capitalised upon by holding demonstrations between the races of correct tractor operating techniques, together with a technical commentary.

4 Conclusions

To date the tractor efficiency programme has proved very successful, largely due to the very practical approach taken. Several aspects of it are novel and the message may well have applications to farmers in other countries.

Providing farmers with information in a form which they can utilise is a common problem often overlooked by researchers and advisers. Following the high investment of time, effort and expense, the New Zealand approach appears to have been successful and will in time produce a return of national benefit.

If the "Tractor Facts" programme can generate as much interest as the Tractor Pulling competition, New Zealand will soon be a nation of expert tractor operators.

References

Martin G A, Sims R E H and **Young R** (1986). Tractor facts manual. Ministry of Energy, Wellington, New Zealand.

Sims R E H (1981). Wheels on ground in New Zealand. *Power Farming,* 60, 6, 73.

Sims R E H and **Barr S J** (1982). How to win a tractor pulling competition. *N Z Journal of Agriculture* 144 5, 31–32.

Sims R E H, Henderson P, Martin G A, McChesney I G, Rennie N and **Studman C J** (1983). On-farm energy supply and conservation. *New Zealand Energy Research and Development Committee Report No. 98,* Auckland University, New Zealand.

The combustion of cereal straw in a fluidised bed hot gas generator

J F Washbourne and B Wilton

Summary

SEVERAL crops that are widely grown generate large quantities of low value by-products: examples include the cereal straws, maize stover and bagasse. One potential use for such materials is as fuel and several methods of utilising them for this purpose — direct combustion, gasification and anaerobic fermentation — are employed. Unfortunately these units tend to have low efficiencies unless they are extremely large.

In industrial circles various processes based on fluidised beds are attracting considerable attention: in one application this approach allows low quality coals to be burned efficiently and, in general , the heat output from a fluidised bed unit will be greater than that of other types of unit of similar size. Fluidised bed driers are also used.

A small fluidised bed combustor was constructed and tested with chopped straw as the fuel. An underbed feeding arrangement through a slotted tube was chosen so that the volatiles could be released slowly and burned within the bed; intermittent fluidisation was also used in order to minimise the amount of fuel elutriation. The unit was found to be self-sustaining and had an encouragingly high efficiency, but it suffered from smoke leak back through the fuel feed system. In a commercial unit it would be essential to design a leakproof feeder that could also be guaranteed to operate continuously because of the low weight of fuel held in the bed at any one time.

John Washbourne

Brian Wilton

1 Introduction

Some ten years ago an article by Wilton (1978) in the Agricultural Engineer described some work in progress at Nottingham in which chopped straw, separated out from dried whole crop cereals, was burned to produce heat with which to dry further whole crop material. The furnace used in this work was of the sloping grate type, in which material introduced at the top of the grate by a screw conveyor burned as it moved downwards; movement of a particular element of straw was encouraged by a combination of gravity, directed combustion air and the ram effect caused by subsequent charges of straw.

John Washbourne is a Consultant Engineer and Brian Wilton is a Lecturer in Agricultural Engineering at the University of Nottingham.

As far as is known only one other unit of this type was constructed — a replica was built to provide the heat required to operate a large continuous grain drier on an arable farm in the north of England. At the time relatively small boiler units — such as those used to heat farm houses — or very large, industrial pulverised fuel burners were available for materials such as straw. Despite the lack of commercial interest, the sloping grate design was regarded as meeting the requirements of the system satisfactorily. In subsequent work at Nottingham by Wilton *et al* (1980) heat exchangers were added so that clean air could be used for drying; a straw pre-drier was also constructed so that undried whole crops could be processed and the resulting straw used to provide heat for drying grain.

The next step by Wilton (1983) was to scale down the sloping grate unit to the capacity required for heating a house and office and to link it to an automatically controlled bulk handling and feeding system for chopped straw. The handling system was based on a self-unloading trailer, fitted with agitators which responded to demands from a thermostat mounted in the heating system. After this, the work turned to the application of a more sophisticated approach to the combustion of 'difficult' fuels such as chopped straw, namely that of fluidised bed combustion.

2 Scandinavian-type boilers

Practically all the straw burned to produce energy in UK agriculture is now fed into boilers and the basic design of these units appears to have originated in Scandinavia where they were used as wood burners. The early units were batch fed and were made to take one, or possibly two, conventional rectangular bales. The controls on these early units were crude, but in time they were improved and continuous feeding equipment was developed in an attempt to increase their efficiency.

The units were then scaled up to accommodate large cylindrical bales and in a recent article in this Journal, Metcalfe (1986) produced a comprehensive report of case studies on ten units of various kinds. Since the publication of this excellent article, the low price of conventional fuels has apparently reduced the attractiveness of waste-fired units. This situation may not continue indefinitely and it can be argued that if oil prices rise, attention in agriculture may again turn towards straw and other biomass fuels as sources of energy.

Metcalfe (1986) drew attention to the low efficiency and extremely variable output of batch fed units, but this may not always be a major problem, particularly if a large heat sink is included as a buffer in the system. On the other hand one would expect that eventually better controlled, more efficient units will take over from the simple types that have so far dominated the scene. It is worth mentioning here that only one of the ten units Metcalfe studied had an automatic firing facility: this was used for greenhouse heating and had an initial cost of £32,000.

3 Fluidised bed combustion

Whereas most methods of burning fuels have been practised for a very long time, the fluidised bed technique is relatively new. It was first used commercially by Winkler (1922) in gasifiers but it was not until the 1950s that it began to be used for a variety of purposes, including heat treatment, incineration and the burning of low grade coal fires (Teague *et al* 1966).

The basic process in fluidised bed combustion is fuel being added to a bed of hot particles (usually sand) through which air is being blown vertically. The temperature is such that the fuel releases its volatiles and these burn either within or above the bed, then the residue will also start to burn. The velocity of the air is sufficient to fluidise the sand/fuel mixture so that it appears to boil; the effect of this action is to allow excellent mixing of the fuel and air and this in turn can lead to highly efficient combustion.

When coal is the fuel, fluidised bed combustion allows low quality coals to be burned effectively. This method of combustion also gives a high specific output of heat (from which it follows that units can be relatively small) and responses to changes in demand for heat can be met rapidly. Lignite, processed peat and waste-derived fuels have been burned successfully in fluidised bed combustors (Hampartsumian *et al* 1983) so it seemed reasonable to investigate the possibility of using straw in such a device. Another possible attraction of fluidised bed combustors is their potential to operate on wet fuels and it is well known that throughout the world there are vast quantities of wet waste materials that originate from agriculture. The possibility of turning some of these into sources of energy was another reason for the work reported here.

Fluidised bed units are not without their problems. One of these, bed fusion, occurs when the temperature rises above the melting point of the fuel ash and, occasionally, above that of the bed material. Unfortunately straw ash tends to have a lower melting point than most coal ashes, so the maximum running temperature of a straw-fired unit has to be somewhat lower than that of a coal-fired one.

A more serious problem with straw and other light fuels is that of the elutriation of particles into the space above the bed. This occurs because the velocity of the fluidising air has to be higher than that required to convey straw vertically: it follows that any light fuel fed onto the top of the bed will never enter it and so a hot bed, produced at start-up by gas or oil burners, would soon go cold. One way round this problem is to densify the fuel by pelleting so that it will behave similarly to coal, but this adds to the fuel cost and may make the whole operation uneconomic. Densification is generally used only as a last resort and in any case some potential fuels may be extremely difficult to densify, even with the addition of large quantities of binders.

The high proportion of volatiles in straw and the rapid rate at which they evolve means that they frequently burn above the bed; this, in combination with the elutriation of low fusion temperature ash, can easily lead to the deposition of fused particles on heat exchanging surfaces downstream from the combustor.

Experience gained by Washbourne (1987) in testing a large commercial fluidised bed unit with pelleted straw — some of it stabilised by the addition of 5% by weight of powdered bitumen — has shown that even distribution of the fuel across the bed is essential. Failure to achieve uniform distribution created localised 'hot spots' where higher temperatures than desirable were reached: one cause of this is the extremely rapid release of volatiles when burning straw, including pelleted material.

When the decision was taken to build a fluidised bed combustor for chopped straw, it was obvious that feeding would have to be below the bed. It was also realised that it might not be possible to run such a unit on straw alone, because of the danger of the bed temperature falling below the critical level. The addition of a secondary fuel, such as coal, would offer a way of overcoming this latter problem should it occur, however such a solution would be highly undesirable as it would mean that two handling systems would be required and the secondary fuel would have to be bought in.

In order to maintain bed temperature the essential requirement is to retain the fuel in the bed for as long as possible and the two ways in which it was decided to do this were:

(i) to make the fuel pass through the bed in a slotted and perforated tube on its way to the discharge point; and
(ii) to fluidise the bed intermittently.

It was thought that design feature (i) would allow the bed heat to drive off volatiles from fuel in the feed tube at a steady rate and that these would stand a reasonable chance of burning within the bed, whilst intermittent fluidisation would reduce the amount of elutriation.

It was intended to use air velocities below the fluidising velocity yet almost sufficient to burn off the volatiles and residue within the bed (some secondary air being supplied separately above the bed) and then at regular intervals to increase the velocity to just above that required to fluidise so that ash would be cleared and bed mixing would occur.

4 The test rig

Experimental fluidised bed test rigs for use with coal and other dense fuels can be as small as 15 cm across and still provide results of acceptable accuracy, but for chopped straw it was considered that a much larger rig would be required. It was thought that the smallest tube in which chopped straw could be conveyed satisfactorily would be approximately 75 mm diameter. The nearest suitable components to this size that could be obtained consisted of a 75 mm diameter cast iron auger (as used in an underfeed solid fuel stoker unit), running in an 80 mm internal diameter Incoloy 800 H tube. The latter tubes are commonly used as sparge pipes in commercial fluidised bed combustors.

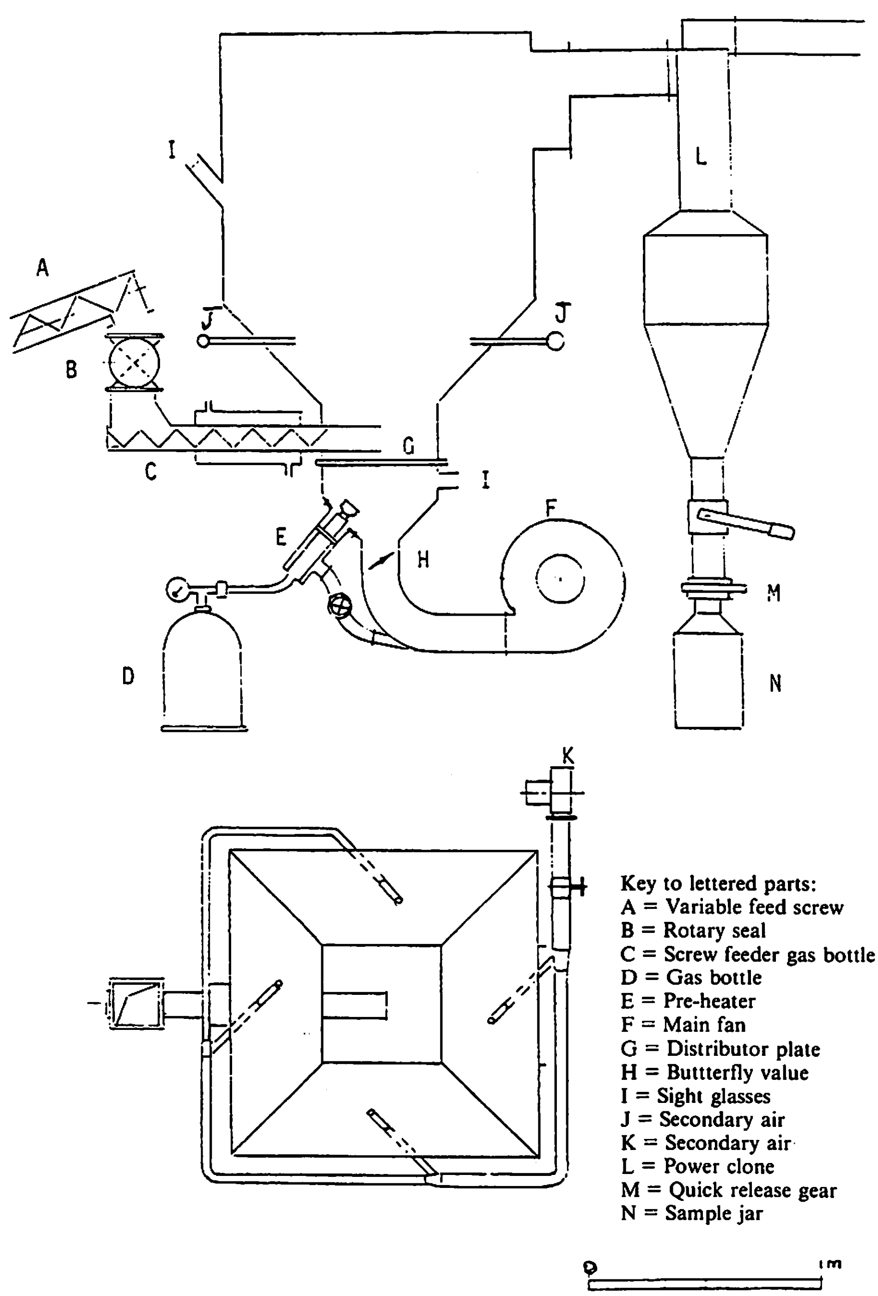
A porous ceramic tile was recommended for the distributor plate that would form the base of the bed and so a 400 mm square tile, 25 mm thick and of adequate porosity was purchased. The tile and feeder were positioned as shown (fig 1) in a castable refractory combustion chamber and plenum. Air for fluidisation was provided by a 5.5 kW high pressure centrifugal fan (0.2 m^3/s at 7 kN/m^2).

Other components of the rig included a variable speed, adjustable cam-driven butterfly valve in the duct between the fan and plenum chamber, a gas burner to pre-heat the distributor tile and bed, a low pressure centrifugal fan to supply secondary combustion air and a rotary valve through which straw could be metered into the feeder.

Above the bed the unit cross-section was increased by a factor of 11 and secondary air was introduced tangentially in an attempt to separate out by centrifugal force any elutriated fuel. From this expansion chamber the flue gases passed into a high pressure cyclone equipped with a quick release sample jar. The rig was equipped with five thermocouples fitted between the plenum chamber and the cyclone, means of measuring both air pressures and flows and flue gas analysis equipment.

When the unit was first run considerable difficulty was experienced in lighting and controlling the gas burner as it was supplied with air by the fluidising fan and operated in a high pressure zone. When this procedure was mastered problems with the porous tile were encountered; no matter how carefully it was heated and cooled, the thermal shock it was exposed to eventually caused it to crack and deposit the bed in the plenum chamber. The castable refractory combustion chamber also cracked badly and eventually both this and the tile were replaced by a stainless steel chamber and plate, the latter carrying 16 perforated standpipes.

Fig 1 Experimental rig for burning straw in a fluidised hot bed generator



5 Experimental results

It took a considerable time to establish the optimum procedure to run the rig. During this time the effect of the addition of up to 10% by weight of washed coal singles was studied, but it was found that this was not necessary if an uninterrupted supply of chopped straw could be guaranteed. The air flows, feed rates, cam patterns and temperatures all had to be determined more-or-less by trial and error, assisted by information from the monitoring equipment.

Eventually the technique was established whereby it took the gas burner some 15 minutes to raise the bed to 520°C, at which stage straw feeding could start. The temperature then quickly climbed to approximately 700°C at which time the gas burner was extinguished. The temperature was then allowed to rise to 800°C by feeding in more straw and it could be held at this level by adjusting the feed rate. Fluctuations in straw feed rate were rapidly followed by temperature changes because of the speed with which combustion took place and the small weight of fuel in the bed at any one time.

In the interrupted fluidisation mode of operation the thermal efficiency of the rig when fed on chopped straw of 17% m.c. was 68.5%, which can be regarded as satisfactory for a small prototype, especially when Metcalfe (1986) stated that 'the bulk of the efficiencies lie in the range of 40–60%.' In the uninterrupted fluidised mode the efficiency was measured at 64.5%.

6 Discussion of results

The work had to stop before a detailed study of the effects of fuel moisture content and changes in the rate and ratio of fluidised and almost-fluidised states could be completed.

The main problem encountered was that of smoke escaping from the feed system: it passed back along the feed auger and through the rotary valve, driven by the high pressure maintained towards the bottom of the bed. A partial remedy to this problem was achieved by placing the fluidising fan intake adjacent to the rotary valve, but even when this was done, conditions in the laboratory soon became unpleasant. It has to be accepted that when the straw is fed in by an auger or a ram device, smoke will pass through the feeder and will have to be collected and fed back by a fan into either the plenum chamber or the zone immediately above the bed. A completely sealed feed system is difficult to visualise.

Whilst proving that efficient fluidised combustion of chopped straw is possible, the work emphasised the absolute necessity of having a closely regulated, continuous supply of fuel. At the other extreme, where large bales are batch fed into simple ovens or boilers, there is considerable latitude in the time when restoking need occur and this may be an advantage in many situations, However, if efficiency and control are important then some more sophisticated combustion system will be required and it has been demonstrated that in such circumstances a fluidised bed unit should not be ruled out.

References

Hampartsoumian E, Gibbs B M (1983). The influence of fuel burning characteristics on the performance of a fluidised bed combustor. *Inter Conf on Combustion in Engineering, Vol 2.* I Mech E Conf Publications, London.

Metcalfe J P (1986). Firing of boilers and furnaces with non-fossil fuels. *The Agric Engnr,* 41, 1, 17.

Teague D S, Wright S J (1966). Members' Information Circular No. 301. British Coal Utilization Research Association.

Washbourne J F (1987). The optimisation of combustion systems for the burning of cereal straw as a fuel. Unpublished Ph D thesis, University of Nottingham.

Wilton, B (1978). Whole crop cereals: harvesting, drying and separation. *The Agric Engr,* 33, 1, 4.

Wilton B, Amini F, Randjbar I (1980). Whole crop cereals: a low cost approach, *The Agric Engr.* 35, 1, 7.

Wilton B (1983). The development of furnace/heat exchanger systems in which chopped cereal straw is the fuel. In *Energy from Biomass: Solar Energy R & D in the European Community* Series E, 5, Reidel.

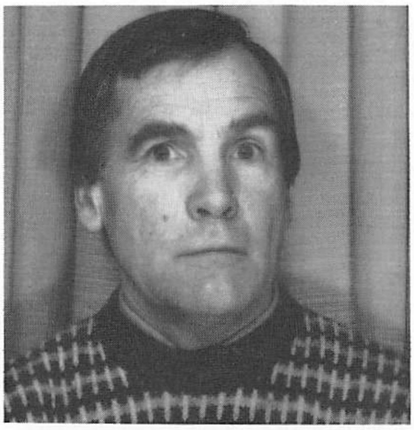
Winkler F (1922). German patent no. 437970.

The development of the Wye double digger

I B Warboys

Summary

THE development of the Wye double digger from experimental and pre-production prototypes to a single furrow machine for soil tillage investigational work is described. The final design needed to operate on a wide range of soils in the UK and overseas and provide comprehensive soil loosening to 0.5 m depth. Field trials have shown that the machine can be operated by a medium size 2-wheel drive tractor (35–45 kW) and that the use of a rotor for sub-soiling can considerably reduce draft requirement and wheel slip.



1 Introduction

The first double digging machine was built at Wye College to mechanise the double digging of experiments previously done by hand (Warboys *et al* 1976). Because of the interest in deep loosening techniques and fertilisation of the subsoil by the Rothamsted Experimental Station (Johnston, McEwen 1984) the National Vegetable Research Station (Rowse *et al* 1977) and the Ministry of Agriculture (Davies 1982) further pre-production prototypes were built at Wye College one of which was used to investigate the power requirement of the implement (Walton, Warboys 1986). As the result of these investigations the design of a single furrow commercial machine was finalised and a two furrow version of the machine was built. This paper describes the development of the single furrow design (fig 1).

2 Requirements

One important criteria in formulating the final design was the need to operate the machine with a medium sized 2-wheel drive tractor (35–45 kW). In consequence it was essential to minimise weight and size so that it could be operated and transported on the tractor's hydraulic system even when fitted with a fertilizer attachment. To enable the implement to be used in soil tillage investigations worldwide, it was essential that the design should be able to work on a wide range of soil types and soil moisture contents with minimal draught enabling wheeled tractor operation with less wheelslip and potentially less soil damage. Particular attention was therefore paid to design of the subsoiling rotor and selection of a gear box to provide a range of rotor speeds.

2.1 Drive and gearbox assembly

To keep costs down the pre-production prototypes used single speed Hi-ton CB gear boxes. However, a multispeed Howard HB-OEM gear box has been used on the experimental version (Walton, Warboys 1986), which confirmed the benefit of having a range of rotor speeds to suit different soil conditions. In the final design a Howard HE-60 Selectatilth gear box was chosen offering 122, 153, 172 and 216 rotor speeds at 540 rev/min engine pto speed. Because this gear box had its output from the left, a left-handed plough version was adopted for the single furrow design. Early prototypes used shear pins in the drive assembly for overload protection but torque limiting clutches were chosen for the final version.

2.2 Frame

In designing the main frame, weight and volume were kept down for export by bolting rather than welding

Fig 1 Wye double digger

Ivan Warboys lectures in Agricultural Engineering at Wye College, University of London, Ashford, Kent.

the box sections in a single piece. The main frame was based on a Y shaped layout with cross bracing by separate front and rear beams to carry the main drive assembly, gear box and jackshaft. Fully adjustable attachment plates and brackets bolted to the front of the Y enabled the attachment of category II tractor lower links. The box section forming the tail end of the frame was drilled to accept a Ransomes leg unit bracket enabling the attachment of a semi-digger Ransomes RCN body with a working width of 360 mm. This could be angled relative to the line of draught by a turnbuckle to permit furrow width adjustment.

2.3 Chain case

The chain case enclosed the drive chain and sprockets which drove the rotor. In order to ensure that the soil in the furrow bottom immediately under the chain case was loosened, the width of the chain case was reduced from 130 mm to 100 mm.

Early prototype chain cases could pivot about their top driven end in plummer blocks welded underneath the main frame, but a depth control stay prevented any vertical movement of the rotor relative to the plough. In consequence, whenever the rotor rode over obstacles in the subsoil this action also raised the plough out of work. To enable independent vertical movement of the rotor in the final design, the chain case was made to pivot about the jackshaft containing the output drive of the gearbox. The chain case was then raised and lowered by a simple hand screw jack and Reynolds chain. To maintain operational depth and support the weight of the chain case when transporting the Double Digger, a heavy duty link chain was fitted as additional support.

2.4 Rotor

On early prototypes pick-type tines were used because they were readily available commercially.

However, because of supply problems and the limited working span between cutting tip and fixing point on the rotor flanges a new rotor design was necessary. On the existing rotor the flanges and tine fasteners were operating in the soil when the rotor was working at its normal depth of 250 mm below the furrow bottom. This caused excessive wear and, under some soil moisture conditions, a build up of soil between the flanges restricting the operational depth. It was therefore necessary to redesign the rotor and the tines to ensure that the flanges and tine fastenings were clear of the unbroken soil.

The modified rotor consisted of two single flanges, one on each side of the chain case, each flange drilled to fasten up to four left hand and four right handed shanks giving 16 shanks in total. For ease and cheapness of replacement each shank carried a reversible cultivator point for soil cutting with a blade mounting angle of 60°. Working diameter of the rotor tip was 760 mm enabling sufficient radial clearance for the rotor hub to rotate above the undisturbed adjacent furrow wall whilst operating in the subsoil at a designed depth of 250 mm below ploughing depth of 300 mm.

Table 1 Force and power requirements on silty loam soil, lucerne stubble (Site 1)

Tillage operation	*Forward speed, m/s*	*Pull, kN*	*Wheel-slip, %*	*Draw-bar, kW*	*Pto power, power, kW*	*Total power, kW*
Plough and sub-soil rotor	0.87	3.6	6.4	3.1	30.9	34.0
	1.03	2.3	2.3	3.0	38.9	41.9
	1.09	1.2	1.9	1.3	46.0	47.3
Plough only	1.14	10.1	19.0	11.5	—	11.5

Table 2 Force and power requirements on silty clay loam, bare ground (Site 2)

Tillage operation	*Forward speed, m/s*	*Pull, kN*	*Wheel-slip, %*	*Draw-bar, kW*	*Pto power, power, kW*	*Total power, kW*
Plough and sub-soil rotor	0.89	1.8	6.7	1.6	14.1	15.7
	1.05	-1.1	2.2	-1.1	29.7	28.6
	1.33	-2.8	2.6	-3.7	31.6	27.9
Plough only	1.09	4.3	20.0	4.6	—	4.6

3 Performance

3.1 Field trials

Field trials with pre-production prototypes had shown that the Wye Double Digger had successfully achieved the design objectives of providing a thoroughly loosened subsoil without mixing it with top soil. As part of a field tillage investigational programme at Wye College, penetrometer data confirmed that the depth of loosening was in excess of 55 cm. Tables 1 and 2 provide data on force requirement and power consumption when operating on two experimental sites. Site 1 (light soil) was on a silty loam in its third year of a lucerne crop, whilst site 2 (medium heavy soil) was on a silty clay loam which had been shallow ploughed some two months previously.

For these trials the Wye double digger was operated by a Ford 7610 tractor rated at a nominal 78 kW equipped with sensors and a data logging package (Wilkes *et al* 1988). This included a modified 3-point linkage dynamometer sensing horizontal, vertical and side forces, a pto torque and speed transducer, wheel slip sensors for each rear driving wheel and a separate 5th wheel to monitor the true forward speed.

The results in tables 1 and 2 show that with increasing forward speed, as the pull force decreased, both drawbar power and percentage wheelslip declined. This contrasts with normal draft implements where pull forces would be expected to rise with increasing speed. On the other hand, as forward speed increased the concomitant increase in volume of soil worked by the subsoiling rotor increased the pto power requirement. As the volume of soil worked increased more thrust was gained from the subsoil. On site 2, the heavier soil, this thrust from the subsoil more than offset the pull force required by the plough on the top soil, (which was loose from an earlier ploughing), giving rise to negative pull values. This contrasts with the runs where only the plough was used without the subsoil rotor operating, where, on both sites, wheel slip values were about 20%.

Conclusion

When operating the Wye double digger little or no thrust is required by the tractor driving wheels resulting in reduced wheel slip lessening the likelihood of soil structural damage by smear and compaction. The negative drawbar pulls on the heavier soil (site 2) depended on the volume and strength of the soil tilled by the subsoil rotor.

These trials confirm that the Wye double digger can be operated by a medium power two wheel drive tractor to a tillage depth of 0.5 m under a wide range of traction conditions. Current models are being used successfully for soil tillage investigational work in Canada, Brazil, South Africa, Sweden and the USA.

References

Davies D B (1982). Subsoil management, *The Agric. Engr.*, 37, 1, 20–23.

Johnston A E, McEwen J (1984). The special value for crop production of reserves of nutrients in the subsoil and the use of special methods of deep placement in raising yields. *Proceedings of 18th Colloquium International Potash Institute,* Italy.

Rowse H R, Stone D A and Goodman D (1977). The Wye double digger. *National Vegetable Research Station Annual Report,* 45–46.

Walton P G, Warboys I B (1986). An Investigation into the power requirements of an experimental Wye double digger. *J. agric Engng Res,* 35, 213–225.

Warboys I B, Wilkes J M, Gooderham P T, Wilkins S M (1976). The development of a double digging machine. *Proceedings of 7th Conference of the International Soil Tillage Research Organisation,* Sweden, 46.

Wilkes J M, Burrage S W, Varley M J (1984). Use of microcomputer technology to improve the performance of tractor/implement combinations. *Proceedings 8th Conference of International Society for Terrain-Vehicle Systems.* Cambridge, 1123–1131.

Selection of a combine

I Yule, T A Copland, J R O'Callaghan

FOR many farmers the most expensive piece of machinery they buy is a combine harvester. The season is short and this high cost machine must be well utilised, if excessive mechanisation costs are to be avoided. Costs can also be high if capacity is inadequate, resulting in large grain losses.

The questions are how do we gauge capacity and what capacity should we operate?

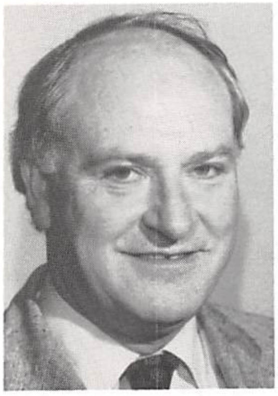
Several factors have been used in the past. Notably cutting table width, but this is unrealistic as most models come with a large range of alternative table widths. Another criterion sometimes used is straw walker area, this again has its limitations because extra straw walker length does not give a directly proportional increase in crop separation. Threshing drum width is now often recognised as the critical factor.

There are generally three drum widths available, approx. 1.05 m, 1.30 m and 1.55 m, which correspond to the combine having 4, 5 or 6 straw walkers. Most manufacturers offer a range of 7 or 8 models based on these three drum widths.

Over the last twenty years a number of researchers have attempted to analyse and model combining costs. Most models start with attempting to assess grain loss through (a) a machine threshing loss and (b) losses of grain in the field through delay (timeliness losses).

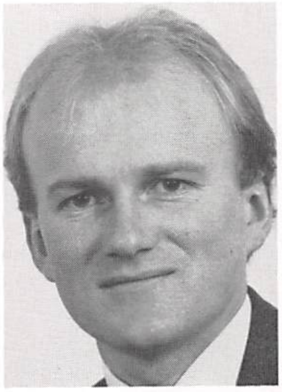
In a study in the north east of England and east of Scotland combining costs have been analysed and an assessment made of the combining costs. Table 1 shows details (including purchase prices for 1983 and 1985) of seven combine sizes analysed. Figure 1 (1983 purchase prices) illustrates the harvesting cost/ha of the most economic combine related to area harvested. Two levels of use were considered, an average of three hours per day and of six hours per day. As can be seen from the diagram, most of the combines appear on the figure.

Ian Yule is a Lecturer at Durham College of Agriculture and Horticulture, Tom Copland lectures in the Dept of Agricultural Engineering, University of Newcastle-upon-Tyne. Jim O'Callaghan is Professor of Agricultural Engineering at the same University.



Jim O'Callaghan

Tom Copland



Ian Yule

Fig 1 Combine system cost, £/ha. 7 tonne crop (1983)

Range of 3 – 6 hours available per day

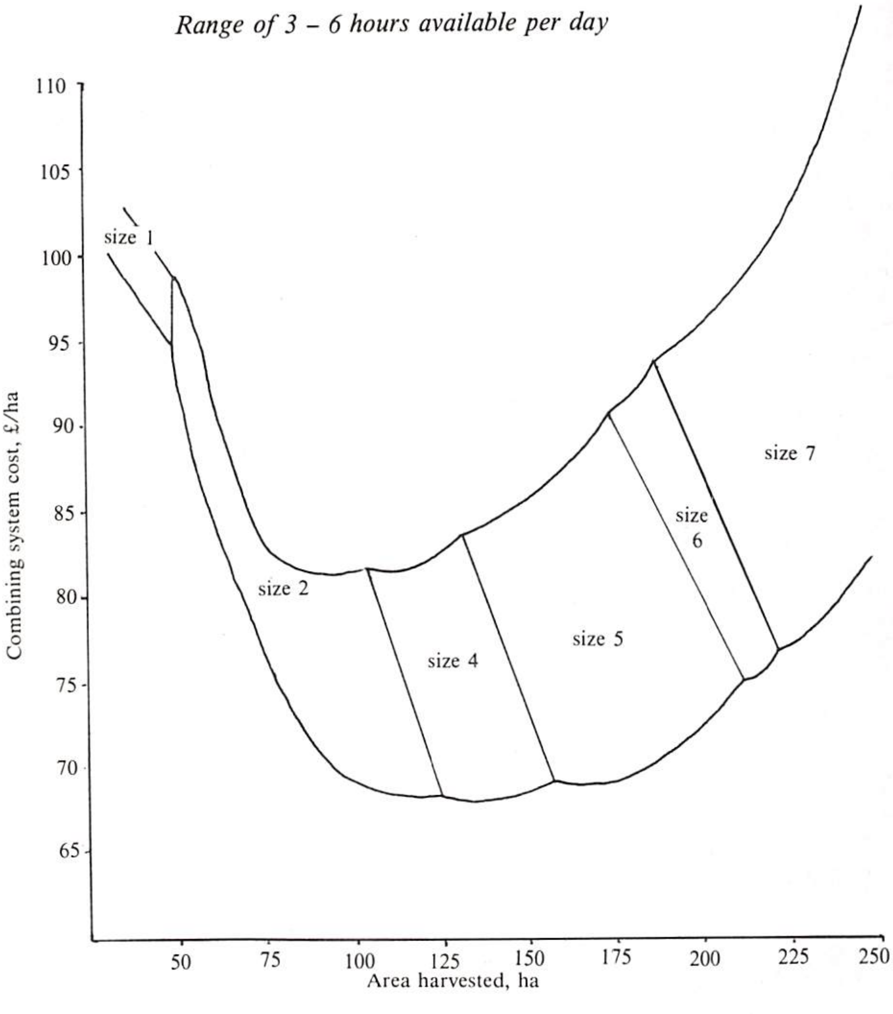


Table 1. Combine costs (from manufacturers price list)

Size	*Quoted capacity t/h straw*	*Price in 1983*	*Price in 1985*
1	4	22000	30000
2	6	25590	35250
3	7	28650	42000
4	9	30600	47400
5	11	39150	50000
6	12	42450	61000
7	14	52650	72000

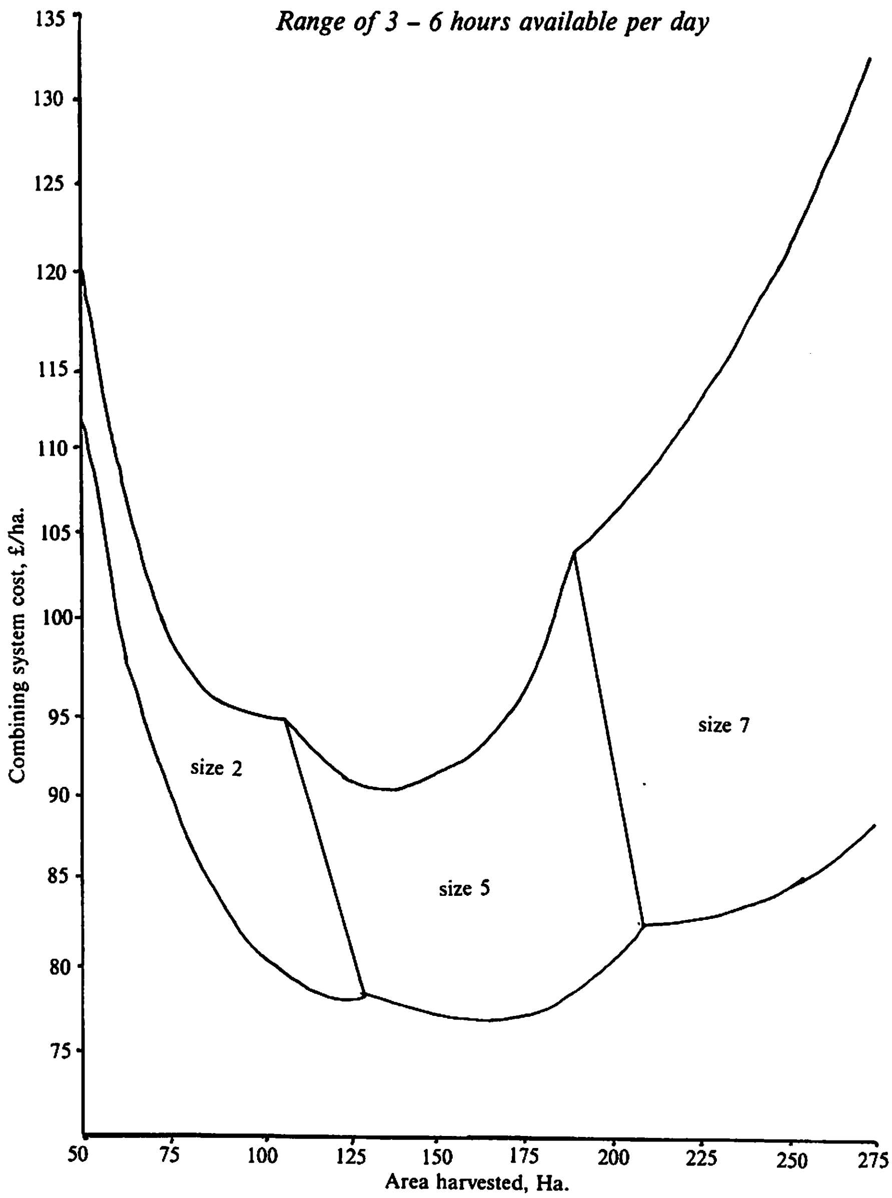


Fig 2 Combine system cost, £/ha. 7 tonne crop (1985)

The same process was carried out for 1985 and figure 2 was produced. The diagram is different in that only three of the combines are represented, sizes 2, 5 and 7. The reason being that for the other models, increased price has not been matched by increased capacity.

It is interesting to note that combine sizes 2, 5 and 7 are the most basic models with 1.05 m, 1.30 m and 1.55 m drum widths respectively.

So, why are so many different models produced when they appear to be uneconomic?

When farmers wish to buy a new combine they should be advised that to buy a model other than the basic type is likely to increase their combining costs nevertheless, they should also look at their requirements in detail. For example, if a straw chopper is required, would the basic model have adequate engine power? A similar question could be asked if a hydrostatic transmission is to be fitted. Is the grain tank of adequate capacity? Is a luxury cab required?

All these items have to be judged against the fact that additional capital input into the machine should be recouped by increased performance if combining is to be carried out economically.

By far the most important factor in costing combine harvesting is the level of fixed cost associated with the machine. In the study carried out, both farms and contracting businesses were examined. It was found that where new machines were replaced every six to seven years the levels of fixed costs were in the order of 80–88% of the total machine cost. Machine costs includes labour, repair and maintenance and fuel. The elements of the fixed costs were depreciation and interest on capital.

Fifty per cent of depreciation occurred in the first three years. For example a £70,000 combine cutting 200 ha per annum replaced every three years would carry a depreciation charge of £58 per ha.

The study was carried out in order to establish what the current costs of harvesting systems were and what was a reasonable capacity for each farm to run.

In order to calculate what was "reasonable capacity" weather data over 13 years for the North East of England was examined to establish how many combining hours were likely to be available. From the analysis it is proposed that the "average daily hours available" (ADHA) for combining is given as:

$ADHA = 6.5 - (d * 0.0306)$
where d = days after the 18th of July

This was the level found for the north east of England, areas further south are likely to have more hours available. The effects of an adverse year where only 60 per cent of average hours were available were also calculated. Although the effect of the adverse years was to push up costs through increased crop losses it had little effect on the actual choice of machine. All the farms in the study had adequate capacity and some have excess, even in the adverse year. Most of the farms could save on cost if they speeded up the combine and accepted slightly higher threshing losses. In some case threshing losses of up to 130 kg/ha in a 7 tonne/ha crop would have been acceptable for the average year.

Figure 3 illustrates the most economic combining system to operate over a large range of areas when new combines are considered and the same idea when 3 year old machines rather than new are considered. In both cases the combines were kept until they had completed ten seasons.

The figure indicates that if second-hand machines are used larger capacity combines can be used over a smaller area thus reducing crop losses.

The dotted lines indicate the level at which it becomes economic to use a contractor. If a contractor is used to replace machines purchased from new then the contractor is the most economic option up to 150 ha. However if second hand machines are used this option is reduced to 50 ha.

So, when looking for your next combine, examine the specifications carefully and try to achieve maximum throughput from your investment.

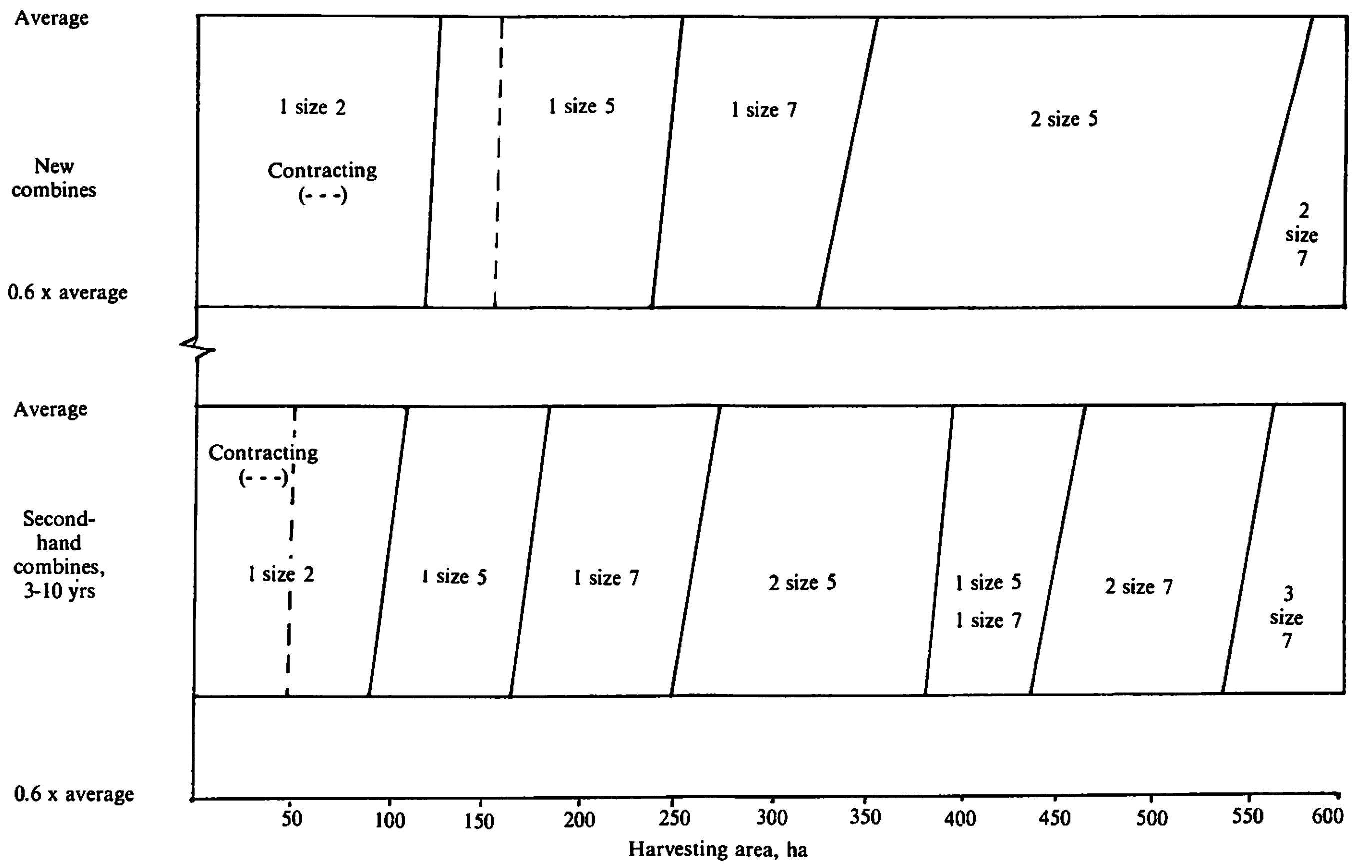


Fig 3 The most economic combining system over a range of cereal areas (in average and 0.6 x average years)

Power potential from performance monitors

S Parish

1 Introduction

MANY tractor manufacturers offer microprocessor based performance monitors on the larger and more sophisticated models in their range. On such tractors, the operators can select from a variety of data displays (see Table 1) providing information which can be used to obtain improved performance. Examples of decisions which could be made to do this are:

a) to increase the travel speed to increase the work-rate;
b) to select a different engine speed and transmission ratio to reduce fuel consumption;
c) to reduce ploughing depth to avoid excessive wheelslip.

Table 1 Sensors and operator inputs required for selected monitor displays

Key:
+ *operator input required for this display*
* *sensor required for this display*
(*) *alternative sensor for this display*

Displays	*Sensors*							*Operator inputs*	
	engine speed	*pto speed*	*wheel speed*	*radar*	*fuel flow*	*exhaust gas temp*	*implement position*	*implement width*	*slip limit*
engine speed	*								
pto speed	(*)	*							
travel speed			(*)	*					
wheelslip			*	*					
slip alarm			*	*					+
work rate			(*)	*			*	+	
distance travelled			(*)	*					
fuel use					*	(*)			
pto overload	*	*							
transmission overload	*		*			*			
counter							*		

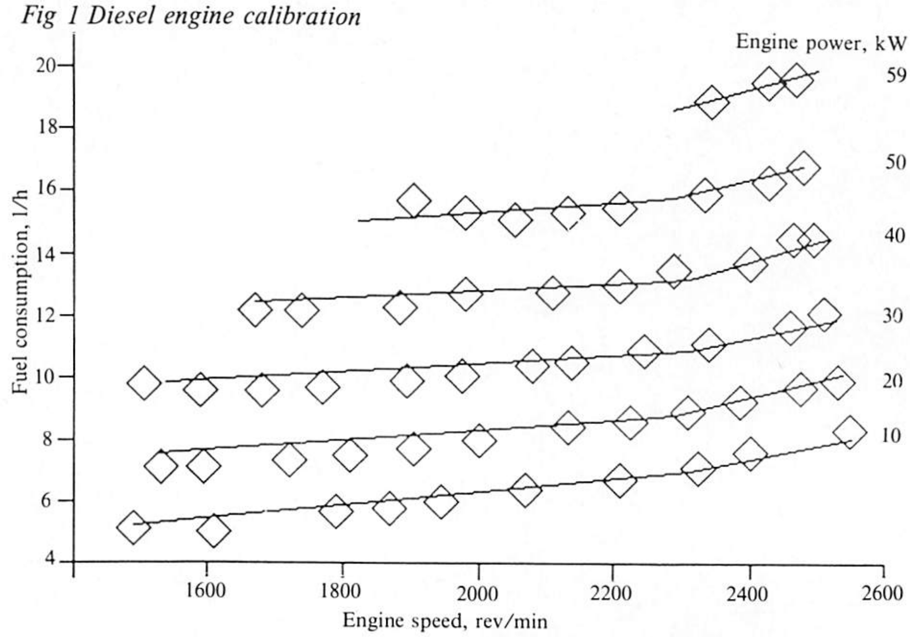
Performance monitors can be used to obtain a better matching of tractor and implement to the required operation. However, the main basis on which a tractor is purchased is the power output, other aspects of performance are usually secondary considerations. It would therefore seem appropriate that performance monitors should indicate the tractor power actually being utilised, so that decisions can be made to exploit that power to the full. This could be done by working at faster speeds with higher loads. An example is the use of a variable width plough on undulating land, or on land with differing soil characteristics. Power data would enable a more appropriate ploughing width to be selected at any one time. Power data is not available on any of the current tractor performance monitors.

2 Engine speed, power and fuel consumption

For a diesel engine there is a unique relationship between fuel used, engine speed and power output (for a specific injection pump setting). A dynamometer test can be carried out to measure these factors, and an engine can be calibrated. An example is shown in fig 1, and if values of any two factors are known then the third can be predicted from this calibration. To be able to predict tractor engine power, a fuel flow-meter and an engine speed sensor must be fitted, and calibration data must be stored in the microprocessor memory of the monitor.

Such equipment is already in use in some monitor systems. Most have sensors

Fig 1 Diesel engine calibration



Steve Parish is a Lecturer in the Agricultural Engineering and Mechanisation Department of the West of Scotland Agricultural College, Ayr.

fitted for accurate engine speed measurement, and one system uses a flow-meter to measure fuel consumption. Another system uses data stored in the microprocessor memory to predict fuel consumption from engine speed and exhaust gas temperature. This is the corollary of the process proposed in this article. In fact exhaust gas temperature and engine speed could be used to predict engine power without fuel data, but the use of a flow-meter gives more accurate data on both fuel and power.

3 Power prediction

Investigations have been carried out into the fuel-speed-power relationship for a 60 kW tractor engine. A positive displacement flow-meter with a digital signal output of 1000 pulses/litre was fitted into the fuel system. The fuel pipes were reconnected to allow only the net flow through the meter. A British Hovercraft Corporation pto dynamometer was used to measure pto speed and power, the load being provided by a hydraulic brake. Data was recorded on cassette tape via a 32k byte microprocessor and interface.

Fuel consumption and engine speed data were obtained from 12 second periods of constant pto power outputs (10 to 59 kW in 5 kW increments), and samples of the plotted data are shown in fig 1. As absolute values of power from an engine depend on ambient atmospheric conditions, the power data was then converted to % of full power data (which is also considered to be the most appropriate display for a tractor operator).

An empirical method was devised to convert the graphical calibration into data suitable for storing in the microprocessor memory. A program was then written to both record pto power data from the dynamometer and to predict the power from the engine speed and fuel consumption data. The results presented in fig 2 show the majority of the predicted data to be within 3% of the measured power values. The accuracy of this prediction could be improved by using a higher resolution flow-meter and a faster microprocessor with a larger memory.

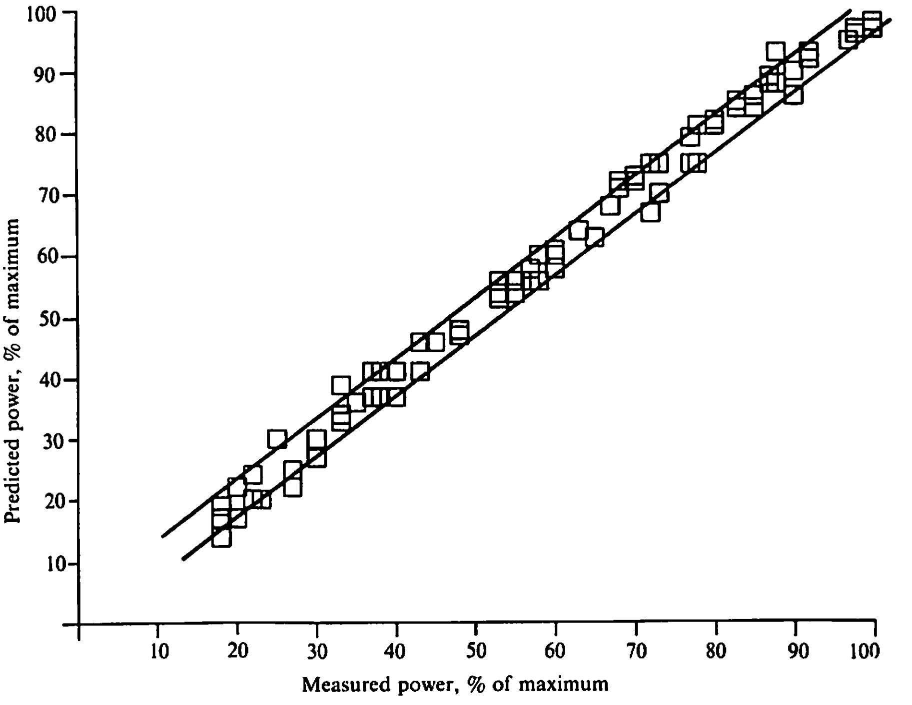


Fig 2 Tractor power prediction

Work is in progress to obtain results from field tests, predicting the power used for different operations from fuel consumption and engine speed data, using a proximity sensor to detect engine speed from the crankshaft pulley speed.

4 Conclusion

Power output data can be provided using the technology currently used in tractor performance monitor systems. Such information would allow the operator to match the tractor speed and loading to its power capability.

It remains to be asked: why has this facility not yet been provided?

Disappointed innovators

J E Colman

THERE is no shortage of inventiveness in Britain, but more and more innovators are disappointed to discover that no matter how brilliant the concept, the pay off may never come.

It is a fact that those who work on farms are prolific inventors. Hardly surprising, that when driving a tractor or cleaning out the yard some better way of doing the job is likely to spring to mind. "Hey presto, here is another innovation and if the chap down the road made his fortune (or so he says), why can't I?" A reasonable query.

Having been personally involved in some of the successes and also in many of the heartbreaks, I think I am well qualified to offer a comment or two.

The sad part is that a discouraged inventor goes back to his corner and may never come out fighting again. Yet he is the sort most industries need. Alas, most of those who managed to earn an honest penny as spare time inventors, will have had a fairly tough ride before banking the first royalty cheque. The exceptions deserve to be congratulated, partly for their luck and also for having had the patience and perseverance to see the job through. By tradition, or so it seems, most inventors die penniless and in blissful ignorance of the success achieved by someone else re-inventing the brainchild of the dearly departed.

This need not be so. The world, not least agriculture, thirsts for innovation.

John Colman is a Marketing Consultant in Farm Mechanisation, was formerly Head of Colman Company Group and is a Past President of AEA.

What is more, it need not be 'hi-tech', often, the simpler the better.

Basically there are two centres for professional research and development. The in-house facilities of the larger companies, associated with learned institutions, which are highly skilled, well financed and know what they are doing. At the other end of the scale there are the small companies, who have ample experience to substitute for academic preparedness and who, if lucky, can harness the skill and inventiveness of a 'user' to work with their own somewhat limited in-house capabilities.

The person with the real problem is the 'user inventor'. There he is, with his innovation, but to prove his point, he may have to produce his own prototype which will irreverently be referred to as a lash-up. Just imagine the poor fellow arriving at the prospective licensee with his half-bedstead, half-early Victorian internal combustion engine. What are his chances to pull off that deal with an up-front payment.

Most inventors think that the first and most urgent task must be to apply for a patent. Important as this may be, it is entirely dependent on many factors, mostly on marketing plans. It should also be realised that a full patent is expensive and may have to be defended by legal action with all the costs that it entails. Guided by a reputable patent agent, the inventor should be able to decide whether a patent will give worthwhile protection against all comers, or if it would be better to concentrate all his funds and effort on attacking the market so keeping competitors at bay.

We all know that "the powers that be" are keen to help all that is small and helpless. But help is needed to identify how best to cater for the real requirements of our tame innovator. Is money the answer? Perhaps, but this will depend for what it is to be used.

Our worthy inventor with his old bedstead will agree that the most valuable aid, grant, handout or whatever designation brings officialdom to his support is that which enables him to get a working prototype built. To provide funds for any other purpose is neither of help to the giver nor the receiver. To encourage an amateur inventor to become the maker or the seller is wrong and, except in very few cases, can only lead to disaster. Make it possible for the inventor to negotiate from strength and he may then have a chance to render service to the industry and benefit in direct proportion.

Thereafter it is a question of facts and usually if there is a need for it, the product will sell.

The Jubilee History of the Institution: 1938–88

IN celebration of the first fifty years of the Institution's life, a history of IAgrE entitled *Agricultural Engineering Perspective* has been written by J A C Gibb*, Hon FIAgrE, at the invitation of the Council. It will be published in the early part of 1988 as a paperback volume of some 120 pages, illustrated by about 20 photographs.

In part, the story of the Institution is virtually the story of the effective mechanisation of British farming up to the present day. It is also an account of the development of engineering in the service of agriculture, from scarcely more than an industry based on the blacksmith's shop to sophisticated professional involvement in a great range of activities on a world-wide scale.

In 1938 there were less than 50,000 tractors and fewer than 50 combines on British farms, while the main source of power was supplied by about a million horses. Against some opposition, a small group of far-seeing enthusiasts met in May 1938 and agreed to set up the body which was to be registered for the early part of its life as 'The Institution of British Agricultural Engineers'.

Throughout the volume, the parts played by many individual members in the development of the Institution — where they have been recorded — are mentioned in the narrative, and the 9-page index includes over 100 names of individuals. Not all contributions by all members are recorded in IAgrE published material, minutes and archives, however, and the author pays tribute in his Foreword to the many whose service to the Institution goes without mention.

Little over a year after its foundation the Institution's activities were interrupted by the outbreak of the Second World War, which immediately intensified the urgency of food production from British farms and greatly emphasised the need for the application of engineering to agriculture. A Provisional Council, under the Chairmanship of Lt Col Philip Johnson, was able to keep the infant Institution's activities going, in spite of all the difficulties of war-time travel and communication, and laid the foundations for rapid development in the post-war period.

Agricultural Engineering Perspective begins with a very brief review of salient developments in the progress of agricultural mechanisation in Britain and overseas. The formative years of the

Institution from 1938 to 1944 are then set against the background of pre-war and wartime farming, based on contemporary accounts and on the Institution's own minutes and records, some of them still in the original manuscript form. From the earliest days the founding members were urgently aware of the need in Britain for education and training in Agricultural Engineering, and their efforts in lobbying successive governments to this end are related. Few of those who have completed degree or diploma courses, or City & Guilds courses, in Agricultural Engineering subjects will be aware of the debt they owe to those early members of the Institution, as is revealed in these chapters.

The rapid development of mechanised farming in the immediate post-war period is reviewed in a chapter on the advance of mechanisation, together with the part played by the Institution's technical meetings and the work of the regional centres — especially, in those early days, those in East Anglia and in Scotland. The emphasis on the need for educational provision in Agricultural Engineering continued, and the steps taken to establish the Institution's own examinations — the National Diploma in Agricultural Engineering, the Graduate Membership Examination and the Institution Examination — are described.

Following the Incorporation of the Institution and the change of its title to the Institution of Agricultural Engineers, in 1959, the period from 1960 onwards was one of consolidation. The Branch network, based on and incorporating the former Scottish, East Anglian and East and West Midlands Centres, grew apace. The thrust for enhanced educational facilities to match the growing opportunities at home and overseas for agricultural engineers, at last resulted in positive action from the government in the establishment of the National College of Agricultural Engineering, in response to the concerted submissions from the Institution, the Agricultural Engineers Association and the Agricultural Machinery and Tractor Dealers Association.

The increasing sophistication and complexity of engineering applications to agriculture, and the Institution's growing membership and interests overseas, led to the holding of the first international Agricultural Engineering Symposium in 1967. Throughout its life, the Institution had published a Journal, which had developed in size, scope and the standard of its contents as the Institution grew in stature. Editorial responsibility had been shared between an informal editorial panel and the Institution's Honorary Secretary in the earliest days, and in due course became formalised with the appointment of an Honorary Editor in 1961, and a full-scale Editorial Panel in 1970. Further developments included the employment of outside expertise in publication and advertising management, and in due course the introduction of the monthly Newsletter, with its own Editorial Panel of volunteers.

With the availability of educational courses at a variety of levels up to Bachelor, Master and Doctoral degrees in Agricultural Engineering, and against the general background in the engineering field of the certification of professional competence and achievement, the Institution had for long held hopes of joining with the older Institutions in the professional registration of suitably qualified members. Much work was done towards this end in committees and in informal discussions with other bodies, and when eventually the Engineers' Registration Board was established, IAgrE was one of the founder members. The door was then opened to registration of those qualified by education, training and experience as either Technician Engineers or Engineering Technicians.

Registration of graduate engineers, such as those emerging from the National College of Engineering, was still not open to IAgrE members, however, and the chapter on professional recognition outlines the stages by which, in due course, the Institution became affiliated to the Council of Engineering Institutions, and thus able to sponsor applications from qualified members for registration as Chartered Engineers.

In its fourth decade IAgrE found itself, together with all the other engineering institutions, confronted by the establishment of the Engineering Council, as had been proposed in the Finniston Report *'Engineering our Future'*.

**Ian Gibb is a Senior Lecturer in Agricultural Engineering at Reading University and a Past President of the Institution.*

The concept of the Engineering Council as an 'engine for change' was immediately supported, and IAgrE was soon to seek recognition by the Council as a Nominated and Authorised body. The listing of the Institution in 1985, as the first of the non-Chartered engineering Institutions to be Nominated and Authorised for all three sections of the Council's Register — in affiliation to the Institution of Civil Engineers for the purposes of the Chartered Engineer Section — marked its ultimate claim to full professional status, short only of its own Royal Charter.

Agricultural Engineering Perspective describes in detail the activities and achievements summarised above, in the context of the events of the time, and with reference to the related personal contributions of Presidents, Secretaries and many others. In the final chapter an attempt is made to indicate the new challenges facing the Institution as it begins its second half-century in a world of food surpluses rather than shortages, and with unparalleled new technical opportunities.

It is hoped that all members will find something of interest, and a source of pride, in this very readable account of their Institution's growth and development, and that many will wish to purchase a copy at the very modest price at which it will be available.

(Information on publication date and the price to members is now available in the Institution Newsletter).

Illustrations

1 Frontispiece: Lt Col Philip Johnson — Founder President

2 The Presidential Badge

3 Col Johnson and Past-Presidents

4 Silsoe College (aerial view)

5 The 'Little Grey' Ferguson tractor, circa 1948

6 Combine testing at Askham Bryan, circa 1946

7 Dr P C J Payne, First Principal of NCAE

8 Professor B A May, Head of Silsoe College

9 Mr J V Fox, President 1974—76, and Past-Presidents outside HQ Offices, April 1976

10 HRH Prince Philip, Duke of Edinburgh, at the Douglas Bomford Third Memorial Lecture on 17th October 1979, with Past-Presidents T Sherwen and J C Turner, Mr B C Stenning (past Honorary Editor) and Mr K Axford

11 R J Fryett, Secretary 1974—85

12 G E E Tapp, Secretary 1985—

13 AFRC Engineering — aerial view

14 Presentation of the MacRobert Award at the NIAE, to Mr J Matthews (Director)

15 AFRC combine stripper-header

16 AFRC broiler harvester

17 SIAE electronic potato separator

18 Silsoe College Library

19 Mr J Matthews, President 1986—88, and Past Presidents, October 1987

20 Dr B D Witney, President 1988—1990