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Pressures for change generate engineering opportunities

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Harvester for coppice willows built at Loughry College, Cookstown, N Ireland, under the direction of Dr Henry McLain. An uprated version is currently under development. (Photo: Loughry College)

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Contents

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Presidential address

The introduction of new technologies

J Matthews

Summary

THE broad range of engineering and associated disciplines involved in the development of systems for producing the world's food are increasingly collaborating and realising the large scope for equipment and process improvement arising from the multi-disciplinary approach. This paper reviews some of the opportunities for new or improved equipment which are derived from advances in several sectors of engineering and science.

Methods of machine design and construction are briefly discussed with some suggestions for ways in which computer-based analytical and design techniques can assist machine functioning and reliability. The greater use of newer materials, particularly plastics, is proposed and it is suggested that there may be scope for a greater availability of standard constructional parts in polymers. Process and mechanism modelling allow both a better understanding and a more effective optimisation of machine design and use.

Developments in sciences associated with agriculture will increasingly provide opportunities for new equipment to be conceived and marketed both for on-farm use and for use in the food processing industry. A greater understanding of the physical properties of agricultural materials and the ways in which these properties or physical processes may be used to identify, characterise and process agricultural produce is discussed. Rapid developments in electronic sensing, computation and communication are considered to be the most important area of advance with many opportunities to improve both the economics of agricultural processes and also to assist in ensuring the quality of agriculture's output.

1 Introduction

A principal purpose of the Institution and of this Conference is to assist the agricultural and agricultural engineering industries by identifying, analysing and promoting new and improved machine types which will commercially benefit both farmer and equipment manufacturers. Other papers to the Conference have substantially contributed to this aim by examining the demands on and opportunities for the farm machinery manufacturers in responding to current pressures on agriculture arising from either economic or social factors. My task is to complement these "problem pull" opportunities by enumerating some of the "technology push" opportunities arising from rapid advances in science and engineering at this time.

A thorough examination of new equipment possibilities is particularly relevant now, with the vital search within agriculture for more economic solutions to the husbandry of crops and animals if profits are not to drop disastrously. The agricultural equipment industry is suffering from reduced trading because of farmers' plight and, if it is to remain a viable industry, must also seek every opportunity to maximise the appeal of equipment to the farmer and grower. The purchase of new equipment will have to be justified by evidence that its use will result in greater savings of cost through either a reduction of input material such as seed, chemicals, or feedstuffs, or, alternatively, a reduction of labour or energy costs. There will be many who will claim that, with low profits, high overdrafts and high unemployment, mechanisation must slow down and perhaps even be reversed. Such arguments can only be met by showing that the improved or increased mechanisation will be cost effective. Fortunately there are many examples where this may be demonstrated. Conversely, the author is unaware of any economic studies which have indicated solutions to today's problems which require a return to less intensive and productive agriculture.

The review of new technological and scientific opportunities for equipment in this paper will encompass constructional materials and design methods, our ability with increased understanding and computing power to analyse and model the performance of components, mechanisms and whole machines, an increased understanding of the physical properties of agricultural materials and greater application of physics, prospects

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arising from advances in agricultural science and biotechnology and, finally, the opportunities afforded by today's possibilities in electronic sensing processing and control. The timescales of development and of the acceptability of the market-place are very difficult to define, and space does not permit proper analysis of priorities.

2 Materials and design

Although both polymers and ceramics are making slow but steady inroads into the construction of farm equipment, on cost and in the majority of cases where there is little penalty from weight or life limitation by corrosion, steels predominate. Advances are likely to come through the application of improved surface treatments including pre-paint surface treatments or plasticised paints (Tope 1985).

With increasing concern about the effect of heavy machinery on soil structures and the ever-increasing width of materials distributing equipment such as sprayers and fertiliser distributors, it might be thought that there would be an increasing use of lightweight alloys which in weight saving and in corrosion resistance would appear to be under-used. On the evidence of use by manufacturers, however, reinforced plastics would appear more attractive. The use in sprayer booms of both glass-reinforced bonded resins and of reinforced polymers may well be a prelude to the use of these materials in structural components for fertiliser distributors, for implements not prone to high, continuous or shock loads such as hay-making equipment, and ultimately to farm trailers and self propelled machines.

Moulded polymers are employed extensively and increasingly for non-structural elements on tractors and self-propelled equipment (McGregor & Creasey 1984). Hoppers and tanks are of plastic construction and a relatively small proportion of chutes, crop or material guides, covers and guards and cabs are built this way. The principal reason why more use is not made, however is the relatively high cost of moulds where production numbers are small. With rationalisation in the industry leading to larger production runs there must be a trend to use more plastic mouldings. There will, however, still be many different design models of machine where numbers individually will not permit economic use of plastic components if these have to be "tailor made". The author believes that machine design would be improved and costs reduced if the scope for standardised moulded design would be improved and costs reduced if the scope for standardised moulded plastic parts — guards, panels, chutes, hoppers and minor structural elements — could be fully exploited.

Where traditional materials are still used, it is perhaps surprising that alternative joining and fastening methods have not been utilised more fully. A good example here is the technique of friction welding which has the advantages of speed, low fixturisation cost and flexibility. It also provides the opportunity to reduce the size of machined components by providing an alternative form of fabrication.

This is only one example of many new welding techniques whose use is beginning to expand; electron beam welding, wire fed Tig welding and laser welding are others which may have agricultural machinery applications as costs reduce further.

Computer-assisted engineering methods will increasingly also have an effect on machine design. The use of computer aided design (CAD) and manufacturing (Marshall 1985), together with the availability of sophisticated computerised analytical methods for structures and mechanisms, should enable these to be designed nearer to the strength or operational optimum, thereby saving materials. I believe that CAD can ultimately at a lower cost, allow a more detailed examination of the options for framework design, for material sizing and for machine dimensions without the design time then becoming excessive for relatively small production runs. Specialist programmes such as those employing finite element analysis will allow structural design to more precisely suit the loads and dynamic stresses that will be encountered in service. This will only be possible however, if adequate recordings can be made of in-service loadings over a sufficiently broad and representative range of the machine's use. This will clearly involve, in many cases, measurements not only in UK farming but also throughout a sample of export markets. The expense of such work is considerable but the sharing of sponsorshp between a number of companies within the EEC, for example, together with some funding from Brussels, could facilitate the collection of adequate information.

The use of kinematics analytic programmes, such as ADAMS, will help in the design of mechanisms. This will allow more complex mechanisms to be developed and incorporated in machines with a greater assurance of their reliability from machine to machine given inevitable production variations. Reliability will also be able to be better assured under conditions of inevitable wear and in addition smaller mechanisms may be contemplated and will surely become important in areas such as robotic crop planting, treatment and handling mechanisms and robot use in connection with animals.

For machines where larger production runs can be anticipated, it is important to undertake either comprehensive laboratory or field testing of machine durability and particularly of fatigue life. The possession of measured in-service loading information will increasingly make the laboratory rig test using electro-hydraulic vibrators more economic than a field test involving a greater labour as well as well as tractor requirement (Harall 1985).

Fundamental changes in power sources for field machines are unlikely. The major developments in internal combustion engines are likely to be the use of electronic controls of fuel injection and timing to enable the torque and the fuel economy characteristics to be manually or automatically adjusted to suit different operational needs, and the use of increasing numbers of ceramic components to reduce wear and improve mechanical efficiency. Electrical battery power does offer prospects for lower power operations. The best potential appears to be with sodium sulphur batteries which will be able to offer three times the operational range of lead acid batteries at half the weight.

3. Mechanism and process modelling

A useful contribution to the improvement of machine performance has generally been possible by analysis and simulation of the mechanisms of a machine or of machine interaction with the process being carried out or materials being treated. However, the scope of this has been restricted by either our limitations to represent the mechanism or process in mathematical terms or by our ability to solve the mathematical equation which describes the actions. Projects of research organisations, universities and to a lesser extent, in industry, have striven to understand better the processes and now there are few pieces of agricultural equipment whose operation cannot be described albeit empirically in mathematical terms (O'Dogherty & Gale 1986). This approach to development has been boosted by the rapidly increased power of computers enabling much more complex equations from theoretical or empirical models to be solved to enable the factors influencing the process to be analysed and optimised. It is impossible in this paper to give a comprehensive review of the way in which such research can be employed to improve further the breed of machinery. It is, however, appropriate to describe representative examples from which manufacturers can examine the probability of this approach, leading to improvements in their own equipment. The examples will be divided into firstly the modelling of processes and then the modelling of mechanisms.

The mechanics of the cutting of grass has recently been explored by O'Dogherty (1981). By experiment, he has been able to derive increased understanding of the way in which both unsupported and supported (restrained higher up the stem) blades of grass are severed on the plant by moving blades of varying thickness and velocity. O'Dogherty's work has shown the benefit of supporting the blade of grass in reducing the velocity of a blade needed to cut it. He has also shown the relative importance of maintaining blade sharpness, and recent work has emphasised the substantial proportion of the energy which is lost in accelerating a grass stem which after separation falls vertically such that the cut stem is accelerated by the moving blade. Other losses are due to large stem deflection and abrasion. Numerical relationships have been established enabling some calculations to be made before mower designs are finalised. As with most of today's models there are many secondary variables which have not been properly quantified and the model tends to represent statistical probablity rather than a certainty of action. This initial single stem model must also be regarded as the first step towards a more realistic and useful one which describes the actions of cutting blades on the masses of stems present in a growing crop and interacting strongly with one another in the cutting action. When the simulations on the computer can describe properly this more practical process, then it is likely that pointers will be given to directions in which grass cutting can be further improved with much of the design of the machine being able to be calculated from the computer model. The probability of advances still to be made is perhaps best indicated by calculations which show the energy empoyed in cutting each stem of grass at present is several times that shown to be necessary in laboratory experiments.

The second example of process modelling is the generation and distribution to the crop of spray chemicals. Work by Dix and Marchant (1984) has employed modelling involving iterative finite difference techniques to describe the way in which droplets will travel from nozzle to crop. The models take into account variations and distribution of droplet size and can begin to show the desirability of achieving certain sizes of droplets of various velocities and hence pressures generated within the liquid, and also to a degree of the use of controlled air movements in the region between nozzle and crop.

Random walk models are being employed to study spray droplet drift away from the machine. In both of these cases, the fidelity and extent of use of models is limited by the need for further understanding of droplet interactions near the nozzle, of variations of wind conditions adjacent to the nozzle and in the vicinity of the crops. Existing work will improve the model and probably subsequently lead to machine improvements through such features as greater use of variable droplet velocities by pressure variation, the use of variable charging rates to give different ratios of droplet attraction compared to penetration, the use of air assisted sprays or air curtains to constrain spray trajectories or, perhaps, the use of positive collectors for drifting droplets.

Some of the other areas where process models exist or are being developed and should be considered by manufacturers for machine development are:

(a) soil mechanics in relation to designs of shares, tines, blades, discs or coulters;
(b) the distribution of particulates such as fertilisers;
(c) the compaction of fibrous materials in balers, waferers, etc;
(d) the separation of crop seeds from the heads as in threshing;
(e) creation of mole drains;
(f) the drying of crops, particularly by hot air;
(g) the solar and climatic drying of crops in field windrows;
(h) the preservation or deterioration of silage related to packing and sealing;
(i) the control of climate in a group of housed animals.

Examples of mechanism modelling include the suspension of sprayer booms against movement likely to be generated by ground irregularities. Nation (1982) and Frost (1984) have developed models which have shown the benefit of both passive and active types of suspension and have also allowed the characteristics of the suspensions to be optimised. Nation's models have used classic dynamic methods for modelling three-dimensional motions of the boom on a travelling and vibrating machine. Frost has extended these models for analysis of active suspensions in which the boom attitude in relation to the ground is sensed and controlled electrically. This work has resulted in a rapid and reliable method of designing suspensions for specific boom designs. The value of these simulation techniques is demonstrated by the achievement of higher frequency, vertical boom movement reductions of the order of 90% with passive suspensions whilst the active suspension is able to eliminate also a large amount of the lack of boom alignment with the ground due to ground undulations.

A rather different type of mathematical analysis and representation has been produced by Dwyer *et al* (1985) to describe the performance of wheeled ground drive systems. This model has been derived largely by experiment, mainly from extensive measurements with the NIAE single wheel tester but has also involved dimensional analysis to identify the equations best describing the process and the effect on the process of the many variables. The large amount of data collected has also permitted figures of accuracy of prediction to be estimated for the equations. The relationships established for the empirical model employ a dimensionless "Mobility Number" which incorporates soil characteristics, as defined by resistance to the insertion of a penetrometer, together with tyre dimensions and deflection characteristics. The equations predicting the coefficient of traction and the coefficient of rolling resistance of a tyre then derive these from the Mobility Number. In this case, the several variables to be considered in designing a system for a powered vehicle include tyre diameter, width and inflation pressure, weight to be imposed on the wheel, number of wheels to be driven, the tracking of one wheel behind another and a specification of the range of soil types and conditions in which the vehicle is to be used.

Other mechanisms models include:

(a) tractor "draught control" systems;

(b) ride vibration on a vehicle operating over agricultural soils;

(c) dynamics of a drill coulter;

(d) the generation and transmission of torques on pto drive lines;

(e) steering forces on vehicles;

(f) air movements created by fans and other devices.

With the increasing number of organisations within the world working in the agricultural engineering field, many new mathematical models are becoming available and existing ones are continuously being replaced.

4. Physical properties of agricultural materials and applications of physics in agriculture

The majority of agricultural activities involve physical processes. The search for a better understanding of them and for their more efficient application is resulting in increasing work to quantify the processes by measuring the physical properties of materials (Anon 1985). Heat, light, electricity and magnetism are all involved in agricultural processes, although the latter perhaps only at the research phase in, for example, nuclear magnetic resonance measurements. Photosynthesis in production growing of crops has to date almost entirely been from solar light and indirect daylight and measurements of optical properties have been largely in relation to greenhouse or crop covering materials. Increasingly, however, it is evident that the optical properties of both growing plants and of produce may be used as measures of factors such as plant health, plant nutrition produce constituents or produce quality. We need to know a great deal more about the radiant and reflective properties of plants for remote sensing and it seems likely that short range sensing, from the tractor for example, will develop over the next decade or two to improve the control of crop husbandry (Taylor 1985).

Near infra red optical sensors have been developed for moisture constituent analysis (Bowman 1985) and if economic tailored wavelength light emitting diodes can be manufactured, they should, in the short term, also be available for other measureable constituents such as proteins or fats. Optical sensors are also likely to be developed for weed detection to allow a selective spray application for crop detection to allow automatic and improved machine guidance, or for shape measurement to allow machine vision to be developed to control robotic and even manual processes. Examples of the latter could include the selection and harvesting of fruit robotically the attachment of milking machine units and perhaps eventually the health status appraisal of animals through interpretation of their postures (Kawamura 1985).

Although the use of "artificial light" has to date been generally limited to experimental work on plants or varietal breeding, commercial scale enterprises have now been established in Japan. The use of so-called "total energy" systems for protected cropping, in which both light and heat is harnessed from high intensity lamps, is now worthy of serious economic and engineering appraisal.

The most obvious example of thermal physics in agriculture is in the drying of crops. A number of models exist for both high and low temperature drying (Bruce 1984, Sharp 1984). These are already used extensively to design grain driers and more advanced ones are able, by incorporating the prediction of the time and temperature pattern of individual grains, to estimate the risk of damage to germination. These models, however, have also been shown to be strongly sensitive to the thermal conductivity properties of individual grain berries. Such properties are difficult to measure but nevertheless if driers are to be designed with assurance as to their effects on both germination and flour baking properties existing work, measuring properties of cereals grains is well justified.

The measurement of acoustic or ultra- or infra-sonic properties of agricultural produce will normally follow the expectation that these will correlate with certain quality parameters and allow the development of sonic instrumentation. There is evidence that the ripeness and the quality of fruit may be indicated this way (Hellebrand 1985). It is also worth speculating, however, on whether the principles of ultrasonic excitation and vibration may be considered as a means of separating seeds from the plant or in discriminating between different seed types. Ultrasonic agitation may also be usable in the mixing of liquids, emulsions or particulates, perhaps in livestock feedstuffs. A study was made of ultrasonic vibration of soil engaging elements to minimise draught forces (Harall & Szilard 1974). Indications were that this vibration expressed moisture from the soil and created some lubrication of the element with consequent beneficial effects but with the relatively low efficiency with which ultrasonic frequencies of movement may be generated, the process is unlikely to be viable.

The electromagnetic properties are again likely to be most useful as a sensor of quality or moisture state. The best example is the extensive use of electrical moisture meters for grains employing either conductivity or permittivity as a correlator of moisture level. Dielectric heating is possible but is unlikely to be economic; similarly the use of high voltage and power electricity to kill weeds is practical but too costly. The response of plants to lower energy electrical fields is an area little researched but might contain useful methodologies. Other applications of physical property variations which come to mind include the use of electrical conductivity as an indication of mastitis, dielectric constant to include frost hardiness of seeds, optical colour detection to separate discoloured peas or beans and the possible use of electrostatics to separate weed seeds from seeds of a crop. The future needs feature strongly processes involving particulates. Fertilisers, seeds and livestock feedstuffs are of a large economic importance and yet we still have inadequate on-line means of measuring total or rate of flows, and know very little quantitively about the effect of their physical characteristics on pneumatic, centrifugal and other transport and dispensing means. Also there appear to be needs to improve their mixing and the mixing of particulates with liquids and emulsions.

An important area where modern measurement and control techniques could be employed if the measurement of physical properties could be advanced is in the soil of a seedbed. The chief requirements of seed are an adequate level of moisture, efficient permeability of the soil to gases and liquids to ensure a proper transport of nutrients and of oxygen to the roots and a sufficiently low level of mechanical impedance to the growth of roots. The development of devices to measure each of these properties during the progress of an implement over a seedbed does not appear to be intractable although in each case considerable problems are clear. If, however, the moisture profile in the soil of the seedbed could be measured using for example electrical permittivity techniques, then planting depth could automatically be adjusted to take account of this profile. If permeability to fluids could be assessed by perhaps the leakage of air from small holes in an element travelling through the soil and in addition or as an alternative, mechanical impedance could be measured by resistive forces on a root size element, the working of the seed bed could be controlled to produce adequate permeability and mechanical characteristics.

5. Developments in agricultural science and practice

The last few years have seen a resurgence of potential and hence interest in biological developments. The word biotechnology has become synonymous with exciting opportunities encompassing possibilities of genetic modifications to plants and animals, the use of in-vitro fertilisation and growth to rapidly accelerate breed improvement and to bring into practice special characteristics, the identification and use of biological methods to pest control and the use of fermentation and single cell methods to manufacture protein or specialised materials. It is tempting to be over-optimistic about the rate of development and availability of these new biotechnological processes. Many of them will require engineering to bring them to a commercial and economic scale, however.

In looking for shorter-term engineering opportunities in relation to plant growth and use, perhaps the most important area is the prospect of using farm or forest grown crops as a source of biomass for fuel or chemical feedstock. One of the most likely areas of development is in the coppice growing of timber as a fuel. The most probable crops would be willow or poplar trees would be clipped rather than sawn at perhaps five-year intervals with the subsequently harvested wood again clipped into short lengths or chipped to produce fuel either in a baulk or compressed package. Mechanisation of coppice harvesting is being studied in Northern Ireland and the development of a "combine harvester" for coppice timber was signalled at the SIMA Show in Paris two years ago.

The production of liquid fuels from agricultural and forestry crops is at the pilot stage in several countries. In Sweden, a plant has been established for extracting ethanol from cereals and a number of vehicles are already running on fuel with the ethanol content. In France, sugar beet is being used as the alcohol source and, in several other countries alcohol is being extracted from sugar beet or cane. In South Africa, the main experimentation is with seed oils.

In New Zealand, lamb tallow is being studied as a vehicle fuel. Although currently low prices for gasoline make the UK economics of alternative from agricultural crops unattractive, it appears almost inevitable that in some parts of the world at least agricultural crops will be used as a serious and major source of fuels. The engineering implications include consideration of changes to the way in which we gather the crop. For example, do we need only the seeds or do we wish to harvest seeds plus the plant material particularly the heads. At the other end of the system, the processing equipment is major and specialised. Experimental equipment designed to ferment wheat or maize to produce alcohol at the farm level has been investigated (Coble 1986) but the economics appear likely to be less favourable than on a factory scale. Experiments are also in progress on the use of crop biomass to create methane through anaerobic digestion. In the UK, the economic prospects do not appear favourable but the manufacturing industry will need to watch for significant markets for this type of equipment in specific overseas countries and, perhaps in the UK, for abattoir and food processing wastes.

There are evident advantages in growing many tree and bush crops, including apples and raspberries, with the branches or canes trained to form a canopy. Uniformity of quality, yield and damage-free harvesting are all claimed for this technique. For the engineer, equipment opportunities include mechanical harvesters, mechanised training and tying of plants, mechanised pruning and specialised spraying equipment.

Also in crop husbandry, it seems probable that bacteria will be used to facilitate such processes as the breakdown of straw following its incorporation. The equipment requirement for this and other uses of bacterial liquids will be to dispense very small quantities by today's standards of a fluid on to the straw, in this application probably during the incorporation process. Other bacterial fluids used as pesticides may need to be dispensed on growing crops. Such tasks will call for precise metering, near to the target dispensing and perhaps special measures to help ensure adhesion to the target.

From advances in animal science one area of opportunity is in the assessment by instruments of the quality and quantity of meat on live animals. The Food Research Institute (Simm 1983) has developed an instrument for use on the hind quarters of cattle and pigs which employs the principle that the velocity of ultrasound correlates with the nature of the meat and particularly the proportions of muscle (lean meat) and fat. Proposals have been made that this principle together with that of ultrasound reflection imaging could be employed to measure the quality of meat on a live animal, using equipment which permits the animal to walk through the apparatus with an integrated reading for the whole body after its passage. Such a device would have a considerable commercial potential in either cattle markets or abattoirs but the technical challenges of development of such equipment are considerable.

For meat carcases, optical devices may be used to characterise muscle and fat with fibre optics for light transmission employed within a needle-type probe to indicate, during its insertion, the amounts of fat and muscle through the carcase cross section. Visual imaging is also being employed to record and analyse the meat/fat ratio on carcases with the consequent image being used as well as for quality assessment, as the basis for robotic cutting and handling of the meat. The mechanisation of abattoir and subsequent meat handling and processing operations offer considerable opportunities for industry participation and subsequently substantial sales of equipment.

In the presence of other papers on animal welfare and on produce quality however, I will not develop this point further. Neither does space permit further excursion into the opportunities offered by food process engineering. Nevertheless, this is an area where agricultural equipment manufacturers might look to diversify. The requirements for hygiene, precision and reliability are extremely high but with so much of our equipment imported there must be scope for further UK commercial involvement.

6. Electronics, sensors and control

This area provides the largest opportunity for further advance in equipment performance and economics: in most cases, this is by the employment of process monitoring and feedback control. The extremely high power to cost ratio of microprocessor based computing, and the savings which can be made of the extensive inputs to agriculture through their more precise use have prompted the economic incentive. Increasingly sophisticated but effective techniques such as adaptive control, self-learning control, expert systems, have rendered electronic control superior to manual management in many cases. In other applications, the performance of a human operator will improve significantly by the provision of electronic sensing of one or more relevant factors.

A good example of where automatic feedback control can perform better than a human operator and is likely to give substantial cost benefits, is in the control of a hot-air grain dryer (Matthews 1963). Variations in grain moisture content at harvest can mean that on some occasions the moisture content needs to be lowered by only 1% or 2%, whilst on others it can be more than 10% with the consequent drying time at fixed air temperature being as little as 20 or 30 minutes in some instances and as much as 2 or 3 hours in others. Even after years of experience it is extremely difficult for a human operator to adjust the throughput rate of grain to achieve a uniform required moisture content after drying. Many years ago the author showed that control systems could be designed to do much better (Matthews 1964). Today with the possibilities of much greater and cheaper microprocessor power, the computer based control action can not only be optimised to achieve a uniform moisture content but also at the same time take into account the need for preservation of germination and baking quality. The financial value of automatic moisture content control can perhaps be judged by reasonable assumption that it may be capable, due to its lower variability, of controlling the grain moisture level on average 0.5% m.c. above that with manual control without exceeding the safe storage level. The user will therefore have at the end of drying approaching 0.5% more weight of grain in his silos and on a farm with a crop of say 1,000 tonnes, the extra 5 tonnes to be sold will be worth £500. Added to this advantage one would make fuel savings from ore efficient drier operation also controlled from the electronic device.

Another recent example of feedback control is a protective chemical treatment device for cereal seed which has been fitted with control to achieve a uniform grain throughput rate and hence, in this case, reduce the variability of chemical additive per unit of grain mass. In this case, variability was reduced by a factor of three. The control of greenhouse vents to achieve a uniform temperature has been shown to benefit from adaptive control which by taking into account wind direction and strength allows temperature excursions to be halved. Alternatively, the control may be set to minimise the amount of vent opening or closing, so reducing wear, whilst maintaining the same temperature uniformity.

It is possible to predict a performance improvement but not at this stage necessarily to show economic benefit in comparison with the cost of equipment, on fitting control systems to almost all agricultural and horticultural equipment. Analysis will increasingly indicate areas where developments and commercial sales will be justified by benefit. Examples where control applications are already justified or will probably soon so be, include improved control of tractor three-point linkage to enhance operational efficiency or depth uniformity of work done, tillage equipment control to obtain uniform tilth or seedbed conditions, drill depth control in response to soil moisture, spray rate control to be proportional to forward speed, ambient temperature grain drier operation related to climatic conditions, animal housing environment to maintain the "lower critical temperature" for the particular stock and automatic pig or poultry separation by weights to maintain uniform sizes within the pen.

Examples have already been mentioned of the use of machine vision. Methods such as image stabilisation or idealisation, already employed in television, will enable moving animals or plants to be imaged. Techniques such as adaptive threshold setting enable boundaries to be located even under changing light conditions whilst perspectively corrected enhancements of the image with three-dimensional techniques will increasingly allow machine vision to approach the discrimination of the human sight (Gerrish 1985). Applications will probably include the characterisation of soils and tilths, or of seeds, the control of crop cutting heights, the location, handling and inspection of fruits, vegetables or eggs, and the identification of animal shapes for shearing or automatic milking. A specialised but still important application of machine vision is the use of close circuit television using either visual or infra-red images for manual interpretation of quality, health or safety during, for example, farrowing. Equipment opportunities exist in this area in the short term.

7 Conclusions

This brief review has demonstrated that there are still many opportunities for equipment development which should lead to economic benefits to the farmer and grower and to good commercial products for the manufacturer. Current research and development is continually producing innovation and commercial opportunities. In general these relate to individual features of equipment which are the subject of a particular research or development project. There is increasing evidence, however, that larger producer and equipment manufacturer opportunities may occur from co-ordinated research and development of systems on a larger scale. In the Netherlands, for example, a large programme has been established to tackle automatic milking involving several manufacturers together with Government and research establishments. The author believes that similar arrangements are being or have been made for other mechanisation systems in France. Club contracts have been used in the UK to enable new technologies to be explored at the pre competitive stage under joint sponsorship. These have not however generally looked at new systems rather than new features. It may be appropriate in areas such as controlled traffic mechanisation, mechanised abattoir handling or mechanisation of tomato growing to try to establish a consortium approach with the companies having different technological and commercial interests, to pioneer and jointly sell complete new systems. In many cases this will be justified by home markets but more frequently commercial attractiveness may lie in sales opportunities to prosperous but industrially less active countries such as those in the Arabian Gulf area.

To maintain parity with and hopefully a lead over foreign competitors, equipment manufacturers must maintain a close interest in, and where relevant employ, electronic systems or equipment. It will be the responsibility of Government departments and research establishments as well as industry to ensure efficient data communication between the individual equipment types on a farm. Standardisation of communication interfaces must be given high priority.

The greater understanding of machine functioning through the construction of computer based models of mechanisms and processes will continue and increasingly indicate where improvement can be made. Judgement is needed to time these advances in a way that commerce and user economics are not penalised by too frequent updates. The author hopes that this paper has shown something of the many opportunities afforded by technology. A much more difficult task is to plan correctly the priorities and that rate at which technology should be allowed to advance the equipment to the mutual prosperity of manufacturer and user.

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Environmental and governmental pressure on agriculture

J C Bowman

Summary

FOR a long time after the Second World War, the agricultural industry in the United Kingdom was encouraged by public support and by Government financial inducement to expand. Over the past ten years, the attitude of both public and Government has changed; the enthusiasm for expansion has gone and been replaced by several new sometimes conflicting objectives. The farming industry do not find it easy to accommodate to these new objectives, particularly when there may be no apparent financial advantage, even perhaps some financial disadvantage, in them. These new objectives include the public's increasing concern about the composition of food and the effect of diet upon human health. They include changing human attitudes to the way in which animals in farming may be kept and slaughtered. They include a widespread concern amongst the public about the use of all forms of chemical and the effect of agriculture on the general environment and the landscape.

The financial pressures on agriculture are causing farmers to consider one of three main options:

(i) to take land out of use;
(ii) to find alternative products of which trees would appear to be the most promising; and
(iii) to alter the level of inputs and outputs and so improve efficiency.

The pressures from the public for changes in the quality of products from agriculture as a consequence of the public's greater awareness of the association between the diet consumed and human health do not appear to offer much opportunity for the agricultural engineer to develop new equipment.

The concern from the public for animal welfare does mean that some systems of animal production may have to be phased out. The agricultural engineer may have an opportunity to develop animal management systems which the public will find acceptable.

There are a range of environmental issues about which the public has considerable concern. These include the effects of cultivation practices on soil erosion, the effects of fertiliser application and the use of chemicals on farms as potential hazards to water supplies, the burning of straw, and finally, the storage and handling of animal wastes. All these aspects of modern agriculture offer opportunities for the agricultural engineer to be innovative and to make improvements to farm practice.

The pressures on agriculture, and the need for agriculture to respond, do offer some opportunities for the agricultural engineer. However, it has to be recognised that since these pressures lead to a conclusion that farming is likely to be less profitable in future, farmers are then likely to be looking for ways of reducing their inputs or increasing their efficiency. There are opportunities for the agricultural engineer to innovate, but he will have to be very aware of the pressures under which farming will operate.

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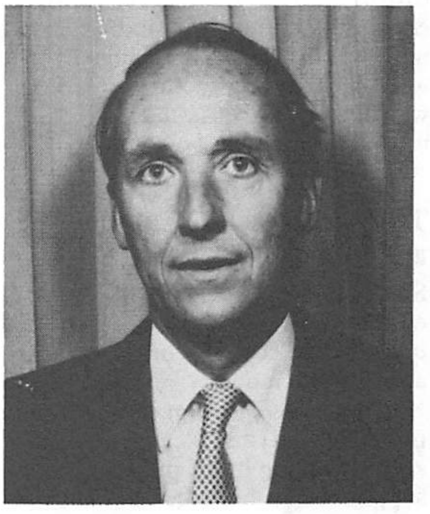

Introduction

FOR a long time after the Second World War, the agricultural industry in the United Kingdom was encouraged by public support and by Government financial inducement to expand. Over the past ten years the attitude of both public and Government has changed; the enthusiasm for expansion has gone and been replaced by several new sometimes conflicting objectives. The farming industry do not find it easy to accommodate to these new objectives particularly when there may be no apparent financial advantage, even perhaps some financial disadvantage, in them. These new objectives include the public's increasing concern about the composition of food and the effect of diet upon human health. They include changing human attitudes to the way in which animals in farming may be kept and slaughtered. They include a widespread concern amongst the public about the use of all forms of chemicals and the effect of agriculture on the general environment and the landscape.

These new objectives are being conveyed into new legislation and into new financial support arrangements for agriculture. The response of the agriculture industry to some or indeed all of these changes is not easy to predict, but it is possible to outline some of the options which the agricultural industry might examine in determining its response to the legislative and financial climate in which it will have to operate. Some of these options include the possibility of using fewer resources in agriculture with beneficial financial consequences for individual farmers. Some of the options may also provide an opportunity for agricultural engineers to innovate and develop new machinery and equipment as well as providing lucrative markets which the agricultural engineering industry might exploit.

The expansive phase of agriculture

Since 1940, and initially as a consequence of food shortages during the Second World War, the agricultural industry in the United Kingdom was encouraged to expand production. This clearly had the strong backing of the public and was supported by a range of financial support measures provided by Government. These measures included forms of guaranteed market prices, as well as grants for improvements to land, buildings and equipment. Certainly in the early years of the expansion the public support derived from the desire to have more food and to have a higher level of national self-sufficiency. Once food rationing, ceased in the early 1950s the doubts about a continuing expansion of agriculture began to emerge. However, for the best part of 20 years these doubts gained little support. Public and Government continued to believe that agricultural expansion, even if it needed to be subsidised, was a worthwhile objective. It is only since the mid 1970s that the doubts have really begun to gain support, and only in the last two or three years that the public have begun to argue strongly against continued agricultural expansion and against using large amounts of public money to sustain and foster that expansion.

To be fair it has to be recognised that the agricultural industry has been very successful over the past forty years in increasing its output. Although the land area devoted to agriculture has not expanded, the output per unit area of land and the yield of individual crop plants and animals have increased substantially. It is perhaps pertinent to observe that yield and efficiency are not the same thing; yield is a measure of output, whilst efficiency is the ratio of yield to the input of resources used. Whilst it is undeniable that yield of British agriculture has increased, there is no good evidence as to whether efficiency has increased. The relationship between yield and efficiency is not a simple one, and though British agriculture is often extolled as an example of a highly efficienct industry, particularly by its own leaders, such statements should be treated with caution. It is for instance claimed that British agriculture is more efficient than most other agricultures in Europe. A close investigation of this statement has not been supportive of the contention but it has to be recognised that the subject of efficiency is a very complicated one. (CAS 1980).

The substantial yield increases in British agriculture have been associated with many changes in the balance of resources used and in the methods and scale of operation. For example, the substantial yield increases have been associated with a reduction in the number but an increase in the size of farms; a substantial reduction in the number of people employed in agriculture but an increase in the number employed in the downstream food processing and distribution industries; many new, high-yielding, disease-resistant varieties of crops and livestock have been bred and used. There has been a substantial increase in the use of fertilisers, pesticides, herbicides and chemicals of all sorts. There has been a substantial investment in machinery and new buildings, but there has also been an increase in the amount of money borrowed by farmers and in the interest charges which they have had to find from farm earnings. To achieve the substantial yield increases it has proved desirable, perhaps even necessary, to improve drainage on large areas of land, to remove ponds, ditches, small woodlands and hedges. There has also been an associated reduction in the accessibility of the countryside to the general public. These changes are factual and can be documented; many of them are also highly controversial.

In the United Kingdom, indeed in Europe and much of the developed world, the output of agriculture is such that for most products production exceeds consumption. Certainly in Europe, nearly all agricultural products are in surplus and the only apparent shortfalls between production and consumption are for high-protein crops for animal feed and some speciality products, as well as those commodities which would normally be grown in the tropics. It has to be recognised that the agricultural production in Europe is financially supported by governments, and in addition it is costing substantial additional sums to get rid of the surpluses. Indeed for some of the surplus production, there is no market at all at any price and certainly not at the production cost pertaining in Europe. Agriculture has become a victim of its own success. It is really not at all surprising in these circumstances that the public and the Government, whose money is used to support the agricultural industry, should begin to question the motives, the objectives and the support methods. Many people and governments now question the level and methods of financial support for agriculture. The attitude can be summed up by asking "Why should we continue to subsidise an industry which produces more than we need and does so by producing food of the wrong composition by methods which we do not find acceptable and by altering the countryside in ways which we do not want?" There is no doubt that British agriculture is well aware of these views and is being strongly self-critical in an attempt to determine how it should respond. Change will not be easy for it will involve costs, and possibly lower returns.

Pressures on agriculture

Financial

The details of financial support provided by the Government and the European community are shown in table 1. It can be seen that the largest proportion of this support is provided for cereals, milk and beef and sheep meat. It is also clear that a much larger proportion of farm financial support goes directly to products than to general farm improvements. These monies are found by the British taxpayer either directly to the British Government or through British Government payments to the European community. In times of substantial food surpluses, it is obvious that those who contribute these sums ask whether they need to be spent at all or could be spent in other ways to

Table 1 Public expenditure under the CAP and on national grants and subsidies

	Public expenditure, £M				
	1981/82	*1982/83*	*1983/84*	*1984/85*	*1985/86 Forecast*
(i) Market regulation under the CAP					
Cereals	242.7	337.2	120.8	370.5	636.0
Beef and veal	41.8	93.8	263.9	343.2	322.2
Milk products	168.8	342.5	561.3	251.4	363.8
Sheepmeat	72.2	126.1	158.3	113.3	95.9
Others	154.1	200.5	270.2	298.3	476.9
Total:	**678.6**	**1099.1**	**1374.5**	**1376.7**	**1893.0**
Against which receipts from EAGGF	698.6	783.7	1132.9	1120.1	1253.4
(ii) Price guarantees Wool and potatoes					
Total:	**17.1**	**8.1**	**9.9**	**−0.2**	**7.8**
(iii) Support for capital and other improvements					
Total:	**173.9**	**206.0**	**220.6**	**202.9**	**144.9**
Against which receipts from EAGGF	26.8	—	46.4	30.0	32.3
(iv) Support for agriculture in special areas					
Total:	**102.8**	**119.6**	**123.5**	**129.7**	**143.1**
Against which receipts from EAGGF	17.0	21.1	21.0	22.5	23.0
(v) Other payments Milk outgoers and weather					
Total:	**—**	**—**	**—**	**5.2**	**26.5**
Grand total:	**972.4**	**1432.8**	**1728.5**	**1714.3**	**2215.3**
Against which receipts from EAGGF	742.4	804.8	1200.3	1172.6	1308.7

Source: Annual Review of Agriculture 1986. Cmnd 9708, HMSO, London.

obtain some of the objectives now perceived for British agriculture. These sorts of views were clearly represented by Mr Body MP in his book entitled *Agriculture: The Triumph and the Shame* (Body 1982). There are very strong pressures indeed to reduce the amount of money spent on supporting agriculture. Reductions in product prices are almost impossible to apply but it seems that small increases are equally unacceptable. The imposition of quotas, price levies and higher quality standards are all indirect means of reducing prices to farmers and the cost of agricultural support to the taxpayer.

In response to reducing product prices in whatever form, the farmer really has three options:

(i) to take land out of use;
(ii) to find alternative products; or
(iii) to alter the level of inputs and outputs and so improve efficiency.

Individually, most farmers are unlikely to take land out of agriculture if they intend to stay in farming. The land most likely to be taken out is marginal land with natural deficiencies such as land at high altitude, north-facing or with poor drainage, or a combination of all three. For the individual farmer, this option is not particularly attractive and it seems more likely that if land is to be taken out of agriculture it will be when a farmer ceases to farm. Already the price of land appears to be falling and more for marginal farms then those in high quality land areas. There have been some estimates recently of the land area likely to be released from agriculture in the next few years because of these financial pressures but there does not seem to be any serious basis for any of these estimates. It seems likely that the fact that agriculture is important to the social structure of the more sparsely populated and upland areas of the country will be taken into consideration in determining changes to agricultural support measures. Whilst, therefore, these areas would be expected to be those where most land would be released from agriculture, it may also be that support policies maintain the land in agriculture albeit at lower levels of productivity. If this is the case, then in addition to land in the upland and sparsely populated regions being taken out of agriculture it seems possible that marginal grade 3 land in other areas of the country may also be taken out of agriculture. Many would argue that taking the pressure off our land area in this way is highly desirable and will be beneficial for other land uses, including forestry, conservation and recreation.

Taking land out of agriculture does not necessarily imply that it will be abandoned, although some may well be. It is more likely that farmers will look for alternative activities for which to use their land. Apart from moves to reduce the output of cereals, milk and beef, together with moves to increase the area of high-protein crops such as field beans, lupins and peas, as well as an increase in some speciality crops, it seems highly likely that there will be an increase in forests and woodlands. This will apply to lowland farms as well as to the uplands, and will lead to a need for considerable expansion in research on agroforestry and for the development of small-scale woodland and coppicing techniques within the farm enterprise.

Over the past 100 years, farming and forestry in the United Kingdom have largely been considered as two separate industries. Forestry on farms has largely been neglected and most of the forestry has been conifer plantations on a large scale in the uplands. The production of timber for a range of uses, including as a fuel source, offer substantial opportunities to farmers. Modifications of conventional forestry techniques and the redevelopment of coppicing are now being examined (King 1984). These developments offer opportunities for the agricultural engineer to develop new equipment and to expand the sale of existing and new equipment.

Farmers faced with the prospect of reduced prices for their products may well examine the possibility of reducing the level of inputs. The possibility of taking some land out of agriculture has already been examined above. The possibility of reducing the amount of labour, fertilisers, machinery and pesticides, as well as reducing the level of capital borrowing, may well be worthy of consideration. The effect of reducing the level of inputs may be to reduce the yield or it may be possible to maintain the yield with lower levels of inputs. Clearly it is necessary to examine whether a reduction in yield consequent on a reduction of inputs is financially advantageous. Clearly, a reduction in inputs whilst maintaining yield is advantageous financially but is not always easy to achieve. The agricultural engineering industry has for many years been trying to find ways in which their products would lead to a reduction in all sorts of inputs, and it is likely that further reductions may be possible.

Certainly some of the changes which result from lower levels of input may be welcome to the general public because they lead to improvements in the environment which will be discussed in more detail a little later.

Nutritional

In recent years, the general public has become more aware of the association between the diet it consumes and human health. Particular concern has been expressed about the adverse effects of relatively high levels of sugar, animal fat and salt intake, as well as the relatively low levels of fibre and fruit intake (CAS 1979, Robbins 1978, Health Education Council 1983). The public are also very concerned about the number of "additives" which are used in food processing. Some of these additives are used as preservatives, and some for colouring and flavourings as well as for maintaining or increasing the content of water, vitamins and minerals. Whilst it is possible to modify food composition during processing, it is also the case that the public are suspicious of processing and are prepared to pay a premium for products which they can consume direct from the farm, or with the minimum of processing. The expansion of health food shops and of the sale of products from organic farming are examples of these sorts of public pressure. Similarly, the changes in consumption of sugar, meat, fat and high-fibre indicate the public's reaction to their understanding of the relationship between diet and human health. The farming community will do well to respond to these changes in public demand but it is difficult to discern any way in which they are likely to provide opportunities for the agricultural engineer.

Welfare

For many years now the public has expressed concern at the manner in which animals are kept on farms. In particular the public has expressed its concern about the housing of poultry in battery cages, various forms of tethering of pigs and veal calves, and indeed for many aspects of the way in which large groups of animals are maintained indoors for productive purposes. The consequence of these pressures has been the development of Codes of Practice for the management and handling of livestock. These pressures continue and there are those who are still not satisfied with the present Codes of Practice; some would even go as far as making it unlawful to keep hens in battery cages and some other forms of livestock management systems. Some people express these pressures by being willing to spend more on purchasing commodities which have been produced by those management systems which they are prepared to accept, thus free-range eggs can be sold at a premium. It has to be said though that other examples of this sort are hard to find.

These animal welfare pressures do offer agricultural engineers the opportunity to develop new methods for housing animals in conditions which are not deemed unacceptable by those concerned about animal welfare. However, it also has to be recognised that the concern of the public with animal welfare issues appears to be being expressed as a reduction in the consumption of animal products. The move to a more vegetarian diet is consistent with a more healthy diet, a diet which does not offend those concerned with animal welfare, and a diet which can be produced on a far smaller area of land. None of these prospects offers much in the way of opportunity for the agricultural engineer.

Environmental

Earlier in this paper, the changes in agriculture associated with its expansion of output were briefly outlined. Several of the changes such as the draining of land, the removal of ponds, woodlands and hedges, the reduction in public access, and the increased use of pesticides and other chemicals are changes which have been widely criticised. Agriculture has also been criticised for reducing the quality of the landscape, for causing widespread pollution of water supplies through seepage of fertilisers and animal wastes into groundwater reservoirs and rivers, and for causing atmospheric pollution through spraying of chemicals and straw burning. In recent years these criticisms have been documented in some substantial and respected reports. For instance, the 7th Report of the Royal Commission on Environmental Pollution published in September 1979 was entitled *Agriculture and Pollution*. A Study Group Report from the Royal Society in 1983 on *The Nitrogen Cycle of the United Kingdom* outlined a number of ways in which agriculture was causing a waste of nitrogen resources. Even more recently a report entitled *Agriculture and the Environment* was published by the Natural Environment Research Council (Jenkins 1984) which outlined in considerable detail many of the consequences for conservation and for land use of the effects of modern agriculture. Most recently the Economic and Social Research Council has published a review of research by Ian Hodge entitled *Countryside Change (ESRC 1985)* (Hodge 1986).

Table 2 has been constructed to indicate the main farm activities and their relationship to a range of environmental aspects which give rise to concern amongst the general public. Those farm practices which cause environmental concern have been given one or two crosses. This is a personal qualitative assessment with no quantitative foundation. Many of these environmental effects are detailed in the reports referred to where recommendations for alleviating the environmental problems are also to be found. Several farm practices give rise to several environmental concerns. It must also be emphasised that some of the environmental effects are persistent and have widespread effects on many species in the environment, thus pesticides which may be sprayed on to vegetation may subsequently be ingested by invertebrates and vertebrates and may even reach man. The purpose behind this table was not so much to

Table 2 Environment Effects

Farm operations	Atmospheric: Smell	Atmospheric: Chemical sprays	Atmospheric: Dust	Atmospheric: Noise	Atmospheric: Disease	Terrestrial: Fire	Terrestrial: Chemical	Terrestrial: Erosion	Water: Chemical	Water: Erosion	Water: Disease	Landscape: Access	Landscape: Visual
Land Maintenance													
Drainage	X	X			X			X	X	X	X		XX
Fencing												XX	X
Hedging and woodland care								X		X			XX
Crops													
Ploughing			X					XX		XX		X	
Harrowing			XX					XX		XX			
Rolling			X					X		X			
Sowing								X		X			
Fertiliser application	X	X					X		XX				
Spraying	X	XX					XX		XX			X	
Combining/harvesting			X		X								
Residue removal:													
burning	X		XX			XX		X		X			X
burying			X				X			X			
chemical treatment	X	XX					XX		XX				
baling			X		X								
Crop storage													
drying			X		X		X						
silage	XX	XX							XX				
Livestock													
Buildings				X									X
Feeding													
Dipping													
Milking/handling													
Muck removal	XX	X	X		XX				XX		XX		
Muck storage	XX	X			XX				XX		XX		
Muck spreading	XX	X	X		XX				XX		XX		X
Animal transport	X		X	X	X								

Severity indicated by number of crosses

examine in detail the environmental effects of agriculture but to highlight those agricultural practices which might be amenable to further consideration by agricultural engineers with a view to producing machinery and equipment which would reduce the environmental damage, and at the same time perhaps reduce the level of inputs required for agriculture.

Examination of the table highlights four aspects of farm operations which are worthy of such consideration. First, cultivation practices including ploughing, harrowing, rolling and sowing contribute to problems of dust in the atmosphere, soil erosion and soil compaction. None of these problems, even in the United Kingdom, is inconsiderable. In recent years minimal cultivation techniques have been developed and adopted with reduction in some of the environmental consequences, but also with the advantage of using less fuel and labour. Some of these minimal cultivation techniques have also had recourse to chemicals for vegetation kill and these chemicals give rise to concern about their effect on soil organisms, on water quality and on animals coming into contact with treated vegetation. An objective for agricultural engineers therefore may be to seek to develop improved methods of crop establishment using minimal cultivation and minimal application of chemicals to destroy vegetation.

A second subject of considerable environmental concern relates to fertiliser application and the spraying of crops with pesticides, herbicides and other chemicals. There is widespread concern, with some foundation, that such chemicals are applied to excess with the consequence that they reach the water reservoirs and the rivers, as well as killing fauna and flora which they are not intended to affect. Farmers may be using more of these substances than they need to obtain high yields, but one assumes that the relationship between the financial return on the crop and the cost of application of fertiliser spraying makes current practice financially worthwhile. Several reports, especially the RCEP Report 1979 and the Royal Society Report 1983, have stressed the need for farmers to reduce the level of application of fertilisers and sprays and to be more careful and precise about the timing of their application. Since only 10% of the nitrogen which is applied to farm crops finds its way into the crops themselves, it is fairly obvious that there is considerable room for improvement in the efficiency with which nitrogen fertiliser is applied to crops.

Third, a major source of concern about the environment stems from the practices used by farmers to remove crop residues from fields. In recent years there have been many complaints about straw burning. In particular, and in a recent report, the Royal Commission on Environmental Pollution 1984 called for the phasing out of straw burning and for it to be made illegal after five years. The handling of crop residues, especially straw, is a major problem and the failure to find thoroughly satisfactory means of condensing and transporting straw means that its use for other than on-farm consumption has been severely constrained. Straw burning, whilst beneficial as a farm practice, is generally unacceptable to the rest of the population, and even when practised within fairly strict guidelines gives rise to offence in the form of dust, smell and destruction of surrounding vegetation. On occasion it has also been a major hazard to traffic on surrounding roads. The agricultural engineer clearly has much to do in examining ways of handling crop residues either for transportation off the field or for incorporation into the soil in ways which do not lead to reductions in the performance of the following crops.

Fourth and finally, table 2 indicates that the handling of animal waste represents practices which cause considerable environmental effect and concern. The handling, storage and spreading of animal wastes cause offence not only to the farmworker but also to the surrounding population. The smell, the disease risk, the potential pollution of water courses, and on occasions the site of animal waste needs considerable further research to reduce these adverse environmental effects. A good deal of research has been done in recent years to try and find methods for treating animal waste but although satisfactory methods do exist most of these are too expensive to be financially acceptable to farmers. Nevertheless agricultural engineers should be encouraged to continue their endeavours to find methods of handling, storing and processing animal wastes in ways which will make good use of those wastes either as fertilisers or as sources of on-farm energy, and in ways which do not give rise to environmental damage and disbenefit.

Conclusions

After a long period of expansion, agriculture in the United Kingdom is now experiencing a range of pressures including the reduction in price for its commodities, a change in the demand for the types and qualities of products which it produces, changes in the methods of managing animals, and not by any means least, pressure from the public to alter its practices so as to improve the quality of the general environment. The public wants to see a varied landscape with trees, hedges and areas of uncultivated land in which a wide range of wildlife can develop and be sustained. The public wants a landscape which is attractive to look at; it wants a countryside in which it can have access to enjoy the scenery and the fauna and flora. The public is less concerned to see more food produced, in fact it would probably be quite happy to see less produced. It would be pleased to see less of the land used for agriculture and more of it devoted to conservation and recreation. It may be that there will be pressure for some of the land in agriculture to be used for forestry, though there are mixed views on this issue, and the public would clearly be unhappy to see large areas of land converted to conifer plantation without appropriate landscaping. The development of broadleaved woodlands and of areas of coppice in lowland Britain may be acceptable.

All these changes, whilst providing challenges and difficulties for the farmer, are what the public want and are prepared to pay for. The continued high level of support for agriculture from the taxpayer in the United Kingdom is not finding widespread support and increasingly means of changing farming support so as to achieve some of the other objectives for land use are being examined. For example, Sinclair 1985, on behalf of the Council for the Protection of Rural England, the Council for National Parks and the World Wildlife Fund UK, has examined the ways in which agricultural support from the Government could be altered to achieve environmental objectives. Sinclair has examined the consequences of these proposed changes for ten different farmers in different parts of the United Kingdom with different types of farm enterprise. Whilst most farms would lose income one or two would in fact increase their income with the changes proposed. The extent to which farmers would be able to maintain their income depends on their ability to switch to other enterprises not normally associated with farming, and on their willingness to adopt management practices which do not maximise output but which maintain a farm environment and landscape acceptable to the general public. In some respects this means that farmers will need to become park-keepers, and some farmers will clearly find this unacceptable, although much less so if it is sweetened by financial incentive. Many farmers may need to become farmer-foresters but this will require advice, training and financial inducement.

The pressures on agriculture, and the need for agriculture to respond, do offer some opportunities for the agricultural engineer. However, it has to be recognised that since these pressures lead to a conclusion that farming is likely to be less profitable in future, farmers are then likely to be looking for ways of reducing their inputs or increasing their efficiency. There are opportunities for the agricultural engineer to innovate, but he will have to be very aware of the pressure under which farming will operate.

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Improvements in animal welfare

J M Randall

Summary

THE need to improve animal welfare provides many opportunities for the agricultural engineering industry. It is likely that some of these will eventually be backed by government legislation ensuring markets for such developments. The entrepreneur searching for product opportunities has only to refer to the published welfare codes and reports of the Farm Animal Welfare Council to discover a wide range of welfare problems requiring engineering solutions. Relevant reports are listed in the paper and examples given of welfare needs which have been satisfied and many which still require innovation. Some which are described are the application of electronics to the individual feeding of sows, which releases them from a life confined to a cramped stall; a new design of family pig pen which gives groups of pigs an opportunity to satisfy many of their behavioural patterns not possible in modern intensive buildings; the need for reliable fire, food and ventilation alarms and fail safe systems; means of achieving uniformity in sheep dipping; techniques to reduce the damage to birds during handling operations; development of better handling of pigs, cattle and sheep during unloading into the slaughterhouse lairage and the need for engineering solutions to reduce the noise in slaughterhouses. A final warning is given that in the longer term, animal products might be produced by cell culture, obviating the need for the animals themselves and it will be the agricultural engineer with biochemical engineering expertise who provides this ultimate solution to animal welfare.

1 Where to seek the opportunities

Never before has the agricultural engineering industry been offered so many product opportunities arising from public opinion as is being offered today through the pressure of the animal welfare lobby.

Recommendations which help to satisfy the important requirements of animal welfare cover many species and all stages of their production; not only whilst being housed on the farm but also during handling, in transit, at markets and at the place of slaughter. A matrix could be drawn up with the species and classes of species on one axis, for example pigs (boars, dry sows, farrowing sows, litters, weaners, growers, finishers), poultry (fowls, breeding stock, hatching, broilers, layers), turkeys (breeding stock, hatching, growers), ducks, geese, quail, cattle (bulls, milking cows, suckling cows, calves, beef cattle), sheep etc. On the other axis of the matrix would be the stages or processes which the stock experience such as handling, penning, housing, transporting, stunning and slaughter. Not all of these would necessarily be relevant to every class of species but where they are, there is likely to be a need to appraise the welfare of the stock concerned and to determine engineering solutions to any problems which exist. There is scope here for all sectors of the agricultural engineering industry; in manufacture, development and research; and instrumentation; for those with previous experience of livestock requirements and those without. Where, then, are we likely to find the clues as to those areas where our own expertise and processes may be applied?

Fortunately for us many of the problems are well documented and spelled out in a number of reports. The challenge is to identify and develop cost-effective solutions to these problems. Apart from numerous conference papers and popular articles in the agricultural press, there are three specific sources of information which provide the background for future developments. The first is the, so called, Brambell Report (Rogers Brambell 1965) which gives an excellent background to the development of intensive livestock systems covering the effects of economic pressures, the move towards specialisation and the development of new techniques. The definition of welfare is discussed at length, both here and in many other publications. A short definition is always simplistic but welfare is a term which encompasses the physical and mental wellbeing of the animal. Aspects such as behaviour, health, productivity, pain, exhaustion, fright, frustration, suffering, stress, distress, discomfort, disease, predators, mutilation, cruelty, restraint and vices are all relevant but very few of them can be evaluated quantitatively using scientific methods. Consequently, as agricultural engineers who need not necessarily become involved in the important philosophical arguments of the welfarists our first source of ideas for product developments to contribute to the solutions of these problems comes in the extensive recommendations of the Brambell Report. These recommendations

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over a very wide spectrum of problems which could have engineering solutions, many of which have already been the subject of advantageous developments. New systems are being developed to allow individual feeding of sows and to give them freedom of movement in a large pen rather than the previous method of tethering animals individually in stalls. Lameness in fattening pigs can now been significantly reduced by the use of well-designed and well-manufactured slats — but it is disappointing to see very many unsatisfactory slats still in use. Research on the general principles of ventilation has given rise to new and better controlled systems capable of improving livestock health and productivity. Methods of housing calves for veal have been improved considerably. With the introduction of relatively cheap polythene film clad tunnel structures the proportion of sheep being housed and given shelter during the winter months is rising rapidly. Nevertheless, not all of these developments have been perfected or optimised and there are many other problems outlined in the report which still require solutions some 20 years later.

The second major source of information is the Codes of Recommendations for the Welfare of Livestock, published as required by the Agriculture (Miscellaneous Provisions) Act 1968: Part I. The latest revisions of these codes are for cattle (MAFF 1983a), pigs (MAFF 1983b) and sheep (MAFF 1977). Draft revisions for the Codes for domestic fowls and turkeys and proposals for new Codes for rabbits, ducks and farmed deer have been prepared and submitted to the Agriculture Ministers. The welfare code for sheep is currently under revision.

The Farm Animal Welfare Council (FAWC 1985a), which is the third valuable source for the agricultural engineer, is also the coordinating organisation for the drafting of the Welfare Codes. However, in addition to these codes several helpful reports have been published covering welfare at the time of slaughter of poultry (FAWC 1982) and red meat animals (FAWC 1984), and the welfare of a farmed deer (FAWC 1985b).

As I am unable to record all of the relevant welfare requirements in this short paper, I strongly recommend that those who wish to contribute to the welfare of livestock by diversifying their product range or development activities should consult the literature. For those already involved with livestock, experience will also be the source of innovation, but beware of being blinkered by the traditional and familar. There are rich rewards for those who seize the opportunities. Some diverse examples are the need to re-design the milking machine to reduce the incidence of mastitis, to improve health and reduce the level of medication through lowering the challenge of pathogens by improved engineering of the environment experienced by the stock, to reduce the physical damage to broilers and other birds during handling and transport, to provide better environmental conditions for all livestock during transport, to reduce noise in the slaughter house by the use of alternative materials, to design more humane stunning equipment and to design housing systems which allow the animal to exercise more normal behavioural patterns.

2 A sample of the opportunities

Having hinted above at the wide range of opportunities available for development by the engineer, I now select a few of them for more detailed consideration. Some of the ideas are already under development, others require someone to grapple with the problem to produce viable solutions. In the first case I try to give a fairly full background to the problem showing how the welfare codes may be used as a source of ideas for the engineer.

2.1 Housing dry sows

Twenty years ago when intensive methods were coming into use for keeping breeding sows, the increase in the use of individual sow stalls was justified on the basis that it prevented bullying, simplified management and allowed control of individual food intake. Despite these advantages, such close confinement continuously throughout pregnancy was not approved and it was recommended that "pregnant sows should not be kept without daily exercise in quarters which do not permit them to turn round freely and in any event they should not be tethered indoors" (Rogers Brambell 1965). Perhaps the agricultural engineer in 1966 would not have been sufficiently astute to act on this warning, but by 1970 much stronger and more forceful recommendations were made (MAFF 1970). It was now recognised that "the good stockman prefers less confined systems and in general it is the less sound producer who resorts to sow stalls as a means of preventing aggression". Thus if the problem of aggression could have been overcome by better stockmanship, or even by giving sows a small 'hiding' cubicle to which they could retreat, then the only remaining major advantage of the tethered stall was its ability to provide individual feeding. Nevertheless, it was acknowledged that the sow stall system was spreading rapidly — an example of an undesirable system which "ought to be controlled by *positive* welfare requirements but which in practice is likely to be subjected only to economic considerations". (In the shorter term, economic considerations did prevail.) The next remarkable thing is that the report describes in broad terms the improved system which was eventually developed, together with an unconditional condemnation of confinement stalls. On welfare and *ethical* grounds, it was recommended that stalls should be used for feeding purposes in conjunction with a yard to which the animals have free access for exercise. Was this *the* opportunity for the engineer? It would have been if the report had not also evaluated the lack of scientific evidence and taken the wind out of the sails of the entrepreneur. "Further research and evidence from this field are essential before a final conclusion can be reached... There is no reason, on present *scientific* evidence why sow stalls should be regarded as unacceptable on welfare grounds." Consequently, the subsequent Code of Recommendations (MAFF 1971c) by-passed the issues stating simply that individually housed sows should be able to feed and lie down normally and that bedding may be advantageous.

So, it was left to the scientist to provide the necessary evidence — a problem with which he is still grappling today. Instead, the cause has been highlighted and pursued by public opinion, the activities of the welfare lobby and the response of the government. By the time the welfare codes were revised and reprinted (MAFF 1983b) it was recognised that the keeping of sows in stalls with or without tethers raised serious welfare problems and alternative systems were strongly recommended. This, the associated national debate and the increasing use of electronics in agriculture prompted action in developing the earlier recommendation of free access to yards combined with individual feeding stalls. The germ of the solution came from an already successful cow feeder for individually dispensing concentrates, originally developed at the NIAE.

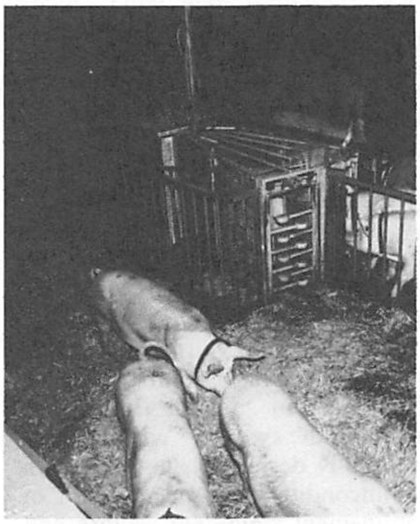

Fig 1 A sow feeding station which provides individual feeding and allows group housing on straw (source Terrington EHF)

Each cow, or now sow, is fitted with a transponder attached to a neck collar giving a separate identification for each animal. The animals are housed in groups, of say 20, and have access to one feeding station. A sow enters the feeding station (fig 1) which automatically closes a rear gate to prevent a second animal entering. The pig is identified through its transponder by a computer controlled system and the required amount of feed is automatically dispensed in several portions. Two minutes after the last portion, which may occur as a result of the completion of the daily feed or the sow not wishing to complete her ration for the day, the rear gate is released and another animal can enter. There are many facilities built into the computer control of the system and many further developments which could be profitably pursued.

More detailed descriptions of the system and its operational performance are available (Large 1983, Edwards 1985). There are at least three manufacturers already developing such systems which call for expertise in computerised control and ingenuity in the design of mechanisms with mechanical, electrical, pneumatic or hydraulic control to provide safe and easy access for individual animals to the feeding station. It was developments in electronics which are now liberating the sow by providing the key to this welfare problem.

2.2 Housing pigs in families

The previous example, provided by specific and narrow recommendations provides an admirable solution to this one problem. But the welfare codes have many other recommendations in relation to the housing of all types of pigs. Perhaps a more radical approach to pig housing is also required and this is one area where a number of behavioural scientists are providing some of the necessary evidence. If we can define the behavioural needs of the animal we are then in a better position to engineer accommodation better suited to their needs. Behaviourists have started by observing the activities of groups of pigs in different outdoor habitats and inferring from their observations those properties which appear to be commonly required by the stock (Stolba and Wood-Gush 1984).

In this study, key nest features were identified. The first is that nests should have an open view enabling the sow to see approaching persons from tens of metres away. This presumably allows the pig time to react to impending danger and gives it a sense of security. Outdoors the preferred nest sites were sheltered against wind and rain and usually had cover on two sides with one open side facing south. Consequently for open-front buildings the desired exposure is to the south. Again, the preferred location of a nest was at the border of two very different habitats (eg grass and bushes, bushes and trees) suggesting that there should be a marked change of conditions between the part of the pen for nesting and the parts used for other activities. Finally the potential nest sites were always remote from the area used for feeding and therefore these should be separated inside a building.

Other features identified were the need for rooting spots, particularly at borders; the use of rubbing trees near but not too close to the nest; the provision of a defecating area about 5 m away from the nest in a border area, although defecation also occurs in somewhat concealed areas whilst foraging; and the need to provide key social features within the family group.

These ideas address a number of the recommendations of the codes so why not design a piggery, based on this information, and incorporating engineering techniques to satisfy the needs of the pig and simplify the tasks of the stockman? The authors have already made proposals (Stolba and Wood Gush 1984) (fig 2) which appear to accommodate the perceived needs of the pigs, but there is further work needed by the engineer to incorporate help for the stockman.

It is proposed that there is a roofed area and an open part of the pen to reproduce a forest border habitat; that the main feeding area is sited away from the nest area; the nest site is sheltered with a view out of the pen; pen walls and permeable farrow rails represent the sheltering of the nest; the nest area is 2 to 3 m in diameter; the defecating area away from the nest, is in the form of a corridor to represent the open areas between the bushes preferred outside; that peat or bark and a levering bar in the rooting area provide scope for wallowing and digging; straw is provided for food and nest building; a rubbing post in the central activity area; the provision of individual feeding stalls and the opportunity for pigs to escape behind removable partition walls to lower social tensions. Social groups of 4 adult sows are housed together in four pens interconnected by the defecation corridor. Farrowing occurs in the pens and the litters grow within the family group. the sow/piglet bond is broken only when the progeny are sold for pork or bacon. In order to avoid mixing of sows, two older and two younger animals are kept together and replacements selected from within the group. The breeding boar relates between three of four familiar family units, staying with each for about 6 weeks.

It will be interesting to see if the features of this habitat are recognised by the pigs and to see if they respond to them in the manner expected. It is hoped that one such system will soon be installed on a British farm and there is encouragement from some welfare organisations to see the system evaluated. Here is a chance for the waste handling, automatic feeding, straw and peat handling and

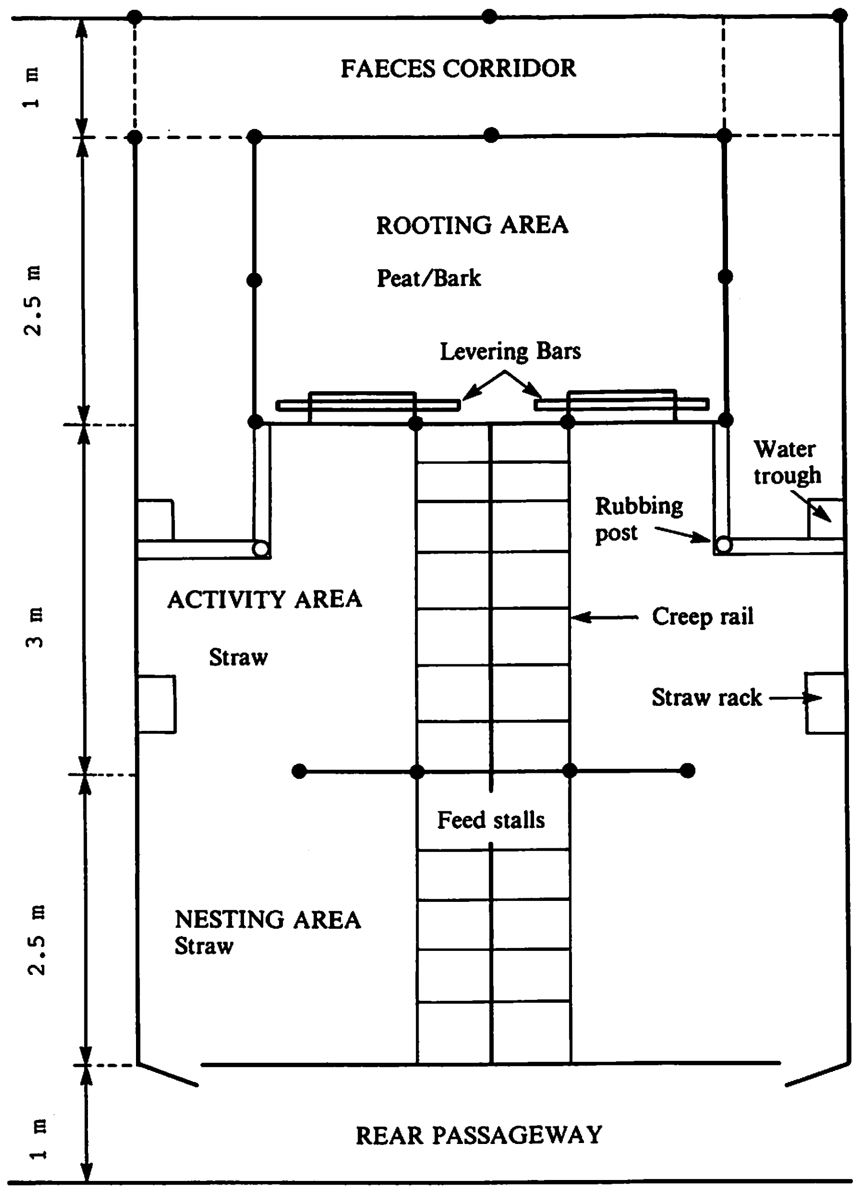

Fig. 2 Plan of two family pig pens which provide some behavioural needs of the stock (after Stolba and Wood Gush 1984)

electronic control parts of the industry to club together to design a thoroughly engineered system meeting many of the welfare needs of the stock. Such techniques could make the individual sow feeder obsolete — or would it be needed in even greater numbers in the family pen?

2.3 Aids for the stockman

Now let us turn to a few specific small items and features of equipment which have been identified or need to be identified to enable the stockman to carry out his duty in satisfying the welfare needs of his stock.

All of the codes recommend the installation of fire alarms, yet when the Farm Animal Welfare Council made draft recommendations in 1985 for proposals for regulations based on the codes they found that it had not been possible to recommend as a regulation the requirement that livestock buildings should be fitted with fire alarms. The reason? Although they were concerned at the losses of livestock occurring as a result of farm fires and felt that a regulation was necessary, no suitable alarm system which would fully protect the safety of the stock could be identified. So here we have a winner: invent a suitable fire alarm and you are likely to have the law behind you, insisting that all buildings should be fitted with one. Incidentally, buildings also require better internal design of gates and passageways to ensure that pigs and other stock can be rapidly released in the event of fire. Today's buildings invariably result in animals being trapped by fire.

Akin to the previous paragraph is the requirement for the adequate provision of food and water, and ventilation and temperature control. Again there are draft regulations that require automatic feeding systems and automatic ventilation systems to be fitted with alarms. Although some suitable systems do exist, there is certainly scope for additional ones which are reliable, fail safe and with facilities for automatic re-setting. During a failure, alternative feeding and ventilation systems may become a requirement.

There are also recommendations that a regulation be made requiring that the internal surfaces, including floors, of all buildings, handling facilities and passageways to which livestock have access should be constructed and maintained in such a way that sharp edges or projections or other features do not cause injury or distress to the livestock. Although this does not identify a specific opportunity for the agricultural engineer, it clearly indicates that he must be mindful of these requirements and ensure that they are incorporated into his developments. Otherwise, one day, you may well find yourself in the paradoxical situation of being prosecuted over a potentially award winning welfare development.

Sheep dipping is mandatory at certain times of year in order to control problems such as fly strike and scab. Effectiveness of the dipping programme depends, not only on timeliness, but also on maintaining the chemical concentration of the dip and ensuring that each animal is immersed for a specified period. As dipping proceeds, insecticide concentration reduces and the normal topping-up process is unreliable and messy. Armed with this knowledge, Coopers Animal Health Ltd. have produced an engineering solution (Stratford 1985) known as the "Powerpack" (fig 3). This metering unit ensures accurate and economic use of dip concentrate as it tops up the mixture in the bath. When attached to a piped water supply, the water flow provides the motive power to a tipping 'bucket' assembly. Each time one of the two buckets is filled with water the assembly tips and in so doing operates a pump to dispense the dip concentrate. The amount of

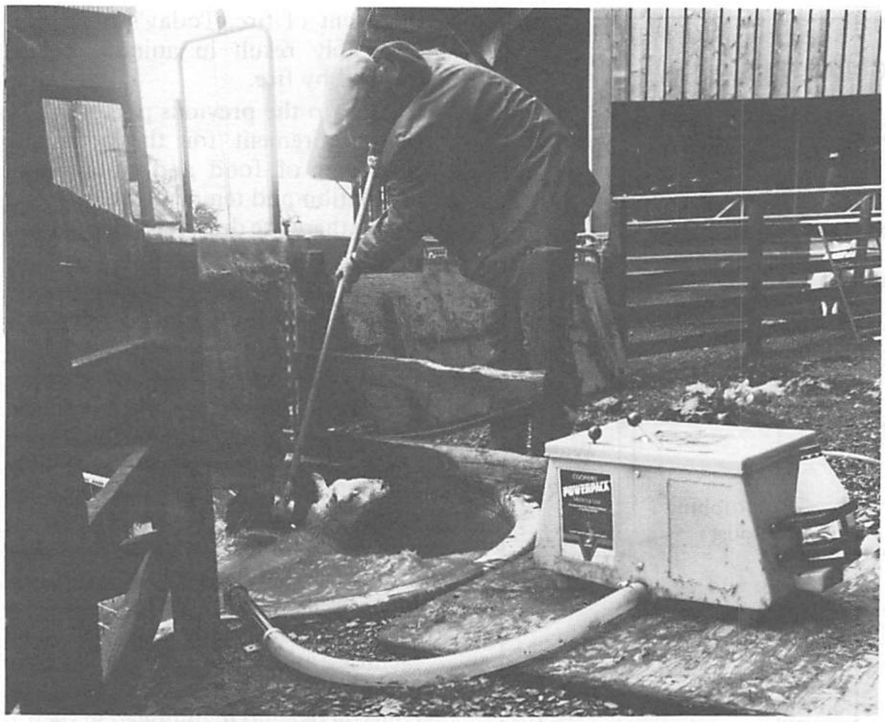

Fig 3 The concentration of sheep dip being maintained by a Coopers Powerpack (source 'Coopers Animal Health Ltd')

insecticide taken out on the fleece is automatically replaced in the dip wash. Electricity is not required. Although this appears to be a neat solution to one aspect of the dipping process, the other aspect of ensuring the correct immersion time still offers a challenge to the agricultural engineer. Who can propose a cost effective, simple and efficient dipping machine which the sheep operate as they pass through, remaining immersed for one minute? Since dipping can be an arduous task, a dipping machine or control system would benefit the welfare of both the flock and the shepherd.

2.4 Bird handling

Most broilers are housed in flocks of about 20,000 and are kept on litter on the floor. they are placed as day-old chicks and within 7 weeks grow to a liveweight of about 2 kg. Having reached this weight, they are caught and taken from the growing site to the processing factory. The present welfare codes say little about the catching process (MAFF 1971a) except that "the proper handling of birds requires skill and it should be undertaken only by competent persons who have been appropriately trained. It should be carried out quietly and confidently, exercising care to avoid unnecessary struggling which could bruise or otherwise injure the birds". Nevertheless, estimates as high as £30M per annum have been made for the loss to the industry by downgrading and one study has shown that of birds condemned because of bruising, 90% of bruises occurred in the 12 h before death and 98% had occurred in the 24 h before death. The main conclusion from this is that appreciable injuries are caused during catching and transport (Kettlewell and Turner 1985). Despite the intentions of the welfare code, little reduction can be expected in the levels of damage to broilers during manual harvesting because it is an extremely laborious task, carried out in very unpleasant conditions and does not attract labour of high quality. Consequently this is one situation where the engineer can explore means of mechanically catching the birds without causing alarm and consequential injury. Machines can be more consistent in their operation and do not tire like the human operator.

To achieve mechanical catching rates comparable with those obtained manually, between 80 and 100 birds must be caught and crated every minute, with minimal bruising or injury. The machine needs to lift the birds off the floor and deliver them to crates for transport. An adequate supply of empty containers has to be maintained for a continuous process. Once filled, the crates are taken from the machine, out of the house and on to a lorry. A system is being developed at the NIAE (Berry *et al* 1984) in which a simple pick-up head gently lifts broilers off the floor without collecting any litter (fig 4). The head consists of three rotors each of which provides a continuous array of radially extending rubber guide elements intermeshing with the guide elements of the other rotors. When the rotors are advanced into a group of birds, the birds are transmitted between the rotors to a centralised discharge located over an inclined conveyor to move the collected birds away for crating. Birds are automatically counted into the crates which are removed from the building by a fork lift truck. A prototype version is still undergoing development and proving trials but appears to be a more practical approach than many of the other attempts to solve this difficult problem.

Even though an answer to this

Fig 4 The NIAE broiler collecting machine designed to reduce injury to the birds (source NIAE)

particular problem will soon be available, there are still several related needs in the handling of poultry. At the factory, birds are placed manually onto the shackling line (a tedious operation causing damage to the birds) and if we have reduced injury at the catching stage then the shackling operation needs to be automated to maintain bird welfare. Here is the chance to develop robotics or automated systems which would have the full support of the welfare organisations and quite likely government legislation, should alternative and humane systems become available. Processors are not averse to automation since all the subsequent operations on the production line are already automated.

What happens to caged laying birds at the end of their useful life? They have to be removed and transported to the processing factory in a similar way to broilers. The manual procedure of removing the birds from the cages and placing them into transport containers is, if possible, even more fraught with welfare problems than during the catching of broilers. Hens are much more active and subject to damage. Perhaps the engineering of removal and conveyor systems for traditional caged laying houses would not be a sound commercial proposition because of the cloud which presently hangs over the caged system as such. The Farm Animal Welfare Council has produced a comparison of the welfare and commercial merits of each system of housing egg-laying hens and state that they do not approve of the cage system on welfare grounds. Although it meets some of their welfare criteria (eg easy to control environment, no risk of predation, birds separated from droppings) the extreme confinement in a physically barren environment denies or seriously restricts the birds' freedom to express natural patterns of behaviour. Combine the need for humane handling of birds into and out of cages, together with separate nesting accommodation, room to exercise, opportunity to dust bathe, and opportunity to escape from other birds and the agricultural engineer has one route to a successful product.

2.5 Unloading and slaughter (red-meat animals)

Pressure for change in the welfare of livestock at the time of slaughter (FAWC 1984) could generate many product opportunities. There are serious shortcomings of present procedures which could be admirably solved by engineering expertise.

Most animals arrive at the slaughterhouse in cattle transporters or farm trucks. Many slaughter-houses have no purpose-built unloading ramps resulting in off-loading to ground level down a steep ramp. Animals are generally averse to steep downward ramps and dislike being faced with a dark access into the lairage building. After a journey they are likely to be unsteady on their feet and the steepness of ramps and the effectiveness of non-slip surfaces are important in efficient unloading. Multi-tiered lorries, hydraulic tail lifts and even hydraulically operated unloading bays are essential to livestock welfare and ease of handling during unloading. Appropriate equipment does exist but the market for it will expand rapidly if present proposals materialise to include purpose-built unloading bays as a legislative requirement for all slaughterhouses. Detailed advice on the design of bays is likely to be given in a new Code of Practice on the welfare of red-meat animals at the time of slaughter. In the meantime there is a considerable body of research into the handling of animals in raceways, on ramps and in lairages on which the engineer should base any developments (Van Putten and Elshof 1978, Grandin 1982/83). For example, in the design of pig handling systems steep slopes (over 15°) and narrowing passageways should be avoided, puddles and shadows should be eliminated, raceways should have solid side fences with open tops, and floor surfaces should allow the animals a sure foot hold. There appears to be some contradiction in the role of light and dark areas, but it may be that animals raised in a relatively dark environment are reluctant to move into the light, whilst those raised in normal or near normal daylight are hesitant in entering an unfamiliar dark area. With pigs and sheep a slightly rising gradient encourages forward movement whereas a downward slope will discourage them.

There are strong recommend-ations for the reduction of noise in slaughterhouses (FAWC 1984). Herein lies a challenge for the materials or acoustic engineer to overcome the noise from self closing metal gates and doors. Cattle, in particular, baulk and retreat when a noisy, self closing gate slams in front of them. The use of steelwork which creates a generally unwelcome noise level is to be discouraged and alternatives which are durable, stockproof and hygienic are sought. Grandin (1980) has reviewed the response of livestock to sounds and concludes, amongst others, that livestock can be handled much more effectively by a quiet handler in a quiet environment than by yelling in a noisy environment.

2.6 The ultimate in animal welfare?

If we project into the future the current trend towards ever increasing demands for improved animal welfare, where will it lead us, as agricultural engineers? We will certainly find increasing difficulty in providing totally humane systems, although the animal behaviourists and animal scientists will provide some of the data with which to work. From time to time it will be necessary to take several steps backwards from current procedures, designs or systems and radically re-think them, taking a fresh approach to solve newly perceived or newly understood welfare shortcomings. It may be that the ultimate in animal welfare is achieved by engineers developing machines and systems to produce meat and animal products without recourse to the animals themselves. Such biotechnologies are already emerging on a laboratory scale and it will be the responsibility of the biochemical engineer to design full-scale environmentally controlled bio-reactors for food production. The present processes for the production of microbial biomass exploit suspension culture techniques for which engineering input is needed to ensure uniform mixing and temperature, to provide control equipment, to maintain stability, to prevent the accumulation of toxic compounds and to keep the process cost effective. This is undoubtedly a role for the agricultural engineer and the warning is to move into these new technologies now, as within the longer term the traditional way of producing animal products may well not continue to provide a source of product opportunities.

3 Conclusions

Product opportunities for the agricultural engineer arising from welfare pressures are widespread and numerous. They can be found in all aspects of livestock husbandry from birth to slaughter. Above all else, many of these opportunities are well documented in the welfare codes and recourse to a few of these will provide the entrepreneur with many problems requiring engineering solutions. Opportunities exist for all sectors of agricultural engineering be it in manufacture, development or research, in sensors, fixed equipment, mobile equipment or buildings. Innovation and adaptation to the changing demands of the industry and the welfare lobby will continue to provide the agricultural engineer with a source of challenging problems. It is our responsibility to meet these challenges and provide the solutions.

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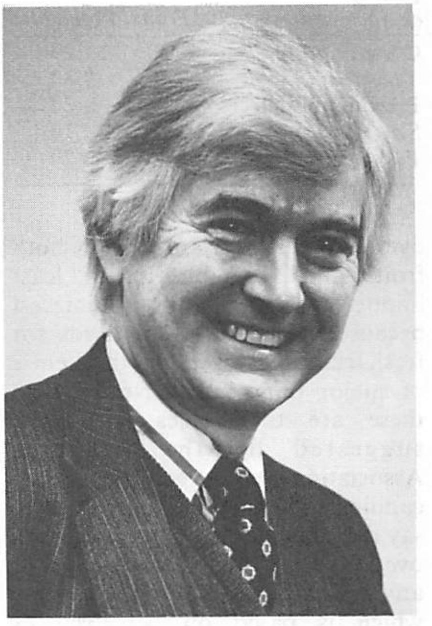
Quality of agricultural products

D Arthey

Summary

QUALITY is an elusive factor and most of us acquire more of it as we become more affluent. The word is difficult to define although an attempt is made to do so in this paper with reference to the five basic parameters of colour, flavour, texture, freedom from defects and size. Examples are given where quality is influenced by these attributes and the factors which affect them are discussed.



Introduction

Quality is that peculiar attribute that the more affluent we become, the more of it we acquire. This applies to nearly all aspects of our lives. For example, as we become more skilful and experienced at our jobs so, in general, we are rewarded more in terms of salary by our employers and this means that we can indulge in more exciting holidays, we can pursue our hobbies with greater fervour, we can accumulate those things around us that we enjoy such as modern or antique furnishings, we can change our homes to suit our improved life styles or enlarge the homes we have, we can dispose of our old second-hand and troublesome cars and buy newer more reliable models that we feel match our images more suitably and we can eat better (or perhaps the word "differently" should be used because, today, the word "better" has several different connotations) than we used to do in the past. We can include wine on our dining tables more regularly and we may more frequently begin our meals with an aperitif and end with a liqueur. In essence, our lifestyles assume a different or improvement in quality.

Definitions

It is the purpose of this paper to discuss the quality of one aspect of our lives and that is food. The title of the paper requires two definitions.

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Agricultural products

First "agricultural products" which to be fully comprehensive would need to comprise meats, fish, flowers, fruits, vegetables, cereals, dairy products and a whole host of miscellaneous items such as honey and herbs, but in this particular instance will be confined to fruits and vegetables for the processing and fresh markets. This is acceptable for the subject of agricultural products because although the crops which will be considered usually come under the heading of horticulture, today most of them are grown on an agricultural scale.

Quality

The second definition required is for the word "quality". This is a very misunderstood term and many consumers believe they know what quality is but find difficulty in trying to define it. Most writers on the subject have their own definition and the author of this paper is no exception. Quality can be defined as follows: it is determined from the relative values of several different characteristics which considered together will determine the acceptability of the product to the buyer and ultimately the consumer. There are many characteristics which have to be taken into account with each product to determine its quality and the individual ingredients of quality differ from product to product and also from time to time. The five basic qualities of any fruit or vegetable product are: colour, flavour, freedom from defects, texture, and size although not necessarily in that order of importance. Size, of course, is one that can be omitted from such products such as tomato paste although it may be important in terms of the size of the container in which the paste is packed. These five parameters are only a beginning and other quality attributes which might be considered are: style, shape, microbiological quality, chemical quality, aspects of the container and its label, freshness, and of course nutritional value or composition.

The measurement of quality in standards and specifications

The many different qualities of any particular agricultural product do not equally contribute to the overall quality image. Many years ago a method of measuring the quality of canned fruits and vegetables was developed at the Campden Fruit and Vegetable Research Association in which the five basic parameters already mentioned were used. It was called Standards of Quality QC6 and all five parameters were employed for all fruits and vegetables except spinach, processed peas and old potatoes where size grading was omitted. The system, which is still in use today in many canneries in the UK is a score card one in which the total number of points awarded is 100. Each of the five parameters does not score 20 points as might be expected and Table 1 shows scores allotted to each parameter.

Thus it can be seen that, in this system, texture in vegetables is considered to be more important than colour or flavour but that colour and flavour are equally important in their contribution to the

Table 1 Scores allotted to the different attributes of quality of canned fruits and vegetables in the UK

	Maximum Score	
Quality characteristic	*Fruits*	*Most Vegetables*
Colour	20	20
Texture	20	30
Freedom of defects	30	20
Size grading	10	10
Flavour	20	20

overall quality image. Size in both fruits and vegetables is of least importance which is of interest because in the EEC standards for fresh fruits and vegetables this item is of major importance. Nevertheless these are the values that were suggested by the Research Association and agreed by the UK canning industry. But that is not to say that they have not been disputed over the years and this is typical of any arbitrary and voluntary scheme which is based on perceived or sensory appraisal of the attributes. In the USDA standards, some of which still employ a scoring system, each product was allotted specific quality characteristics and each characteristic given a score which was unique to that product. Nevertheless with any one product, some characteristics had a higher maximum score than others and therefore the definition of the relative values of the different characteristics stands.

The definition requires these characteristics to be considered together, in order to ascertain the general quality of the product. The assessment of one characteristic alone is not sufficient to determine quality. The product may appear perfectly acceptable in terms of colour and freedom from defects but may be tainted. Similarly a product that has an excellent flavour may not even be served at the table if it does not have an acceptable appearance. All the factors which are of importance must be considered and considered together. The final quality verdict will depend on all the characteristics achieving an acceptable level. Very often this is taken as a measure of grading. In canned fruits and vegetables, the QC6 scoring system already discussed is used as a basis of grading and products which achieve a total score of over 90 may be called Campden Grade A*, over 80 may be Campden Grade A, and over 70 may be Campden Grade B but under 70 the product is Sub-standard. In fact, the system is a dual grading system because, in addition to achieving an overall total score to reach a final grade, there is a prescribed minimum score for each quality item for each grade which also has to be achieved to attain the grade.

For frozen vegetables a different Campden system is used in which freedom from defects plays a major part in determining the final grade. Colour, flavour and texture are also incorporated into the specification but they are not scored. Defects of different defined categories are measured and checked against a tolerance for defects table. If the level of each defect does not exceed the permitted tolerance for a particular grade and provided colour, flavour and texture are also acceptable then the product is graded. If, however, a Campden A grade is sought but one defect level exceeds the tolerance level for this grade then the product is down-graded to Campden B provided of course the defect level does not exceed the tolerance for Campden grade B also!

Standards and specifications for fruit and vegetable products be they canned, frozen or fresh are designed to measure and grade quality so that buyers can determine whether products are acceptable to their retail outlets or customers. Because they are all performing the same function, they are usually quite similar. Different outlets will demand different criteria: for example, buyers of canned food may include in their standards their requirements in terms of can size and specification as well as the composition of the brine, syrup or other covering medium; whereas, frozen food buyers will include in their specifications the type of packaging required and the composition of ingredients in terms of vegetables and styles of products such as stew packs.

In a presentation such as this, only an overview can be given because of time and space. It is therefore not possible to consider all the different quality parameters in detail. However, a few of the more important attributes are worthy of further attention.

Some important quality attributes

Nutritional value

Nutritional value or composition of our foods has become extremely important in our modern society and hardly a day goes by without reference in the press to the relationship of the foods we eat to our health. Indeed, in recent months we have seen a number of official reports dealing with healthier eating. There was the NACNE report which drew up guidelines for health education in Britain. Then there was the COMA report which dealt with diet and cardiovascular disease and more recently the British Nutrition Foundation has produced a simple document telling us what it's all about. It explains the differences between saturated and unsaturated fats and the importance of dietary fibre and carbohydrates. On the back of this NACNE report we read the words "bump up your use of fruits and vegetables – they taste good and do you good". As a more sophisticated shopper emerges we find a greater interest in health products and label disclosure of additives.

Freshness

The image of freshness is closely associated in the mind of the consumer with the previous quality of nutritional value but the term is not easy to define. Many of our fresh foods are not fresh at all; by the time they reach the retail outlets they can be several days old and unless precise steps have been taken to prohibit deterioration their qualities may have declined considerably not only in visible but also in invisible parameters. Very often processed vegetables and fruits are much fresher than so called fresh products and the British Frozen Food Federation has as its slogan "you can be sure is fresh if its frozen". True freshness is probably most closely related to proximity to harvest and the sooner the natural deteriorative processes have been stopped and preserved either by canning, freezing or cooking the fresher the commodity. Of course, the ageing process can be slowed by temperature and modified atmosphere and, by this means, the perceived fresh qualities can be retained for longer. The cool or chill chain has been developed to try and ensure that fresh produce is presented to the consumer in peak of condition. This is achieved by ensuring that field heat is removed rapidly from the produce very often by vacuum cooling. Thereafter, the produce is stored in the packhouse cool store and distributed at chill temperatures. Problems arise when the chill chain is broken or when chilled produce is stored at ambient in retail stores. It would also be interesting to know how fluctuating temperatures affect shelf life and quality. Today the importance of fresh products in the market place cannot be disputed and large retail outlets will often display such produce for the consumer to see as soon as she enters the store.

Colour

Colour is a major aspect of attractiveness and is therefore important to the consumer in deciding the acceptability of the product. Very often colour is dependent on maturity or how ripe the product is but, of course, variety or cultivar will also largely determine colour. Apples are affected by both maturity and cultivar. Culinary varieties are expected to be green and red apples are not usually acceptable for cooking. For dessert purposes, a red apple is preferred unless the consumer has been educated to understand that the orange russet colour of Cox's Orange Pippin means a superb flavour and that the green of a D'Arcy Spice Pippin is also indicative of a unique pleasant flavour. It is interesting to note that some strawberry varieties are naturally so dark red that consumers believe them to be overripe. Most vegetables are expected to be green and a yellowing of broccoli heads and outer leaves of Brussels sprouts is indicative of ageing. Some vegetables are naturally yellow, in which instance the colour is fully acceptable and sought after. For canning, vining peas which are pale green are considered to be the best because the naturally pale hues allows artificial colour to enhance the appearance of the product. For freezing, however, dark green varieties are used because the product relies on its natural colour to attract the consumer and pale green peas would be less acceptable.

Colour is usually determined by eye although equipment does exist for the measurement of colour in agricultural products. The most sophisticated means are the colour meters which give precise measurements but it is sometimes difficult to relate these back to day to day requirements. One product where instrumental colour measurements are made regularly is tomato paste where the redness of the product will determine whether it is acceptable to the buyer. Sometimes fans or colour charts are employed but the non-uniformity of colour of biological material makes it very difficult to use them effectively.

Where sensory assessment of colour is used, a trained judge will sub-divide it into hue, tint, uniformity and brightness. Uniformity is very important in certain products particularly where they have been processed and an appreciation of brightness is more easily explained if the converse dullness is considered. Brightness should enable the product to sparkle. In the Campden system, word descriptions of colour are given for each product, perfection achieving the maximum score with increasing divergence from perfection achieving increasingly lower scores.

Flavour

Flavour is an attribute we seem to appreciate more as we age. Certainly our children appear to appreciate the basic tastes of hamburgers and chips whereas, as we grow older, we tend to appreciate the more subtle (if sometimes powerful) flavours of currys and sauces and different types of meat and fish dishes. It is generally recognised that there are four basic tastes which can be detected by the human palate: sweet, sour, salt and bitter but in addition we can distinguish more than 10,000 odours so we should be genuinely able to experience great pleasure and satisfaction from the flavours of the foods we consume.

The causes of natural flavours of fruit and vegetables and how they can be modified and altered is an enormous subject and we cannot begin to consider it in any depth in such a brief presentation. Perhaps the first major distinction in flavour perception when we eat fruits and vegetables is whether it is natural or tainted. Taints, which are foreign flavours, and off-flavours, which are natural but unacceptable flavours, may be caused by pesticide residues, over-maturity, delay between harvest and processing, faulty preparation or treatment, or contact with faulty packaging material. They often cause us to reject the foods without further thought. These are the extremes of flavour unacceptability but within the acceptability range there may still be flavour differences within the same crop or product. For example, different cultivars may give subtly different perceived flavours and different maturities of the same crop will often give different flavours. We may even add flavours to our foods to change the perceived sensation for example we add sugar to acid fruits, salt to vegetables and some of us like mint in our canned peas.

In the past, retailers have sought to provide us with products that look good but which may not be very flavourful. There is evidence now that they also want to get the flavour right as well but this is not so easy because each of our individual preferences is different. Presumably the retailer will have to ensure that he presents to the consumer those flavours which are most universally appreciated and any eccentricities which individuals of us might have to be satisfied by products from our own gardens.

Whereas degrees of colour and texture are relatively easy to describe, flavour differences are not except for sweetness, bitterness and similar basic tastes. Standards therefore have not detailed this quality and any attempts at descriptions have been fairly rudimentary. We now have, however, a tool which is increasingly used for this process called profile analysis. It requires a highly trained and skilled team to identify descriptors in the nominated product. Once trained, the team can very accurately describe the flavour of that product and indicate all its subtle nuances. In fact, the results can be drawn out in a profile star which is as good as a blue print of that products flavour (fig 1).

Texture

It has already been indicated that texture is another of the important characteristics of quality. Texture will not only apply to the degree of tenderness or toughness of the product but also the wholeness of the units. The perception of texture may be assessed instrumentally, between the fingers or in the mouth. The tenderometer is a very good example of an instrument which is routinely used to determine the texture quality of vining peas for canning or freezing. The tenderometer reading obtained is not only dependent upon the maturity of the pea crop but also up on the conditions of vining in the field. Hand shelled peas regularly have a tenderometer reading five points greater than the same crop when mechanically vined. In the USA, a fibremeter is used to

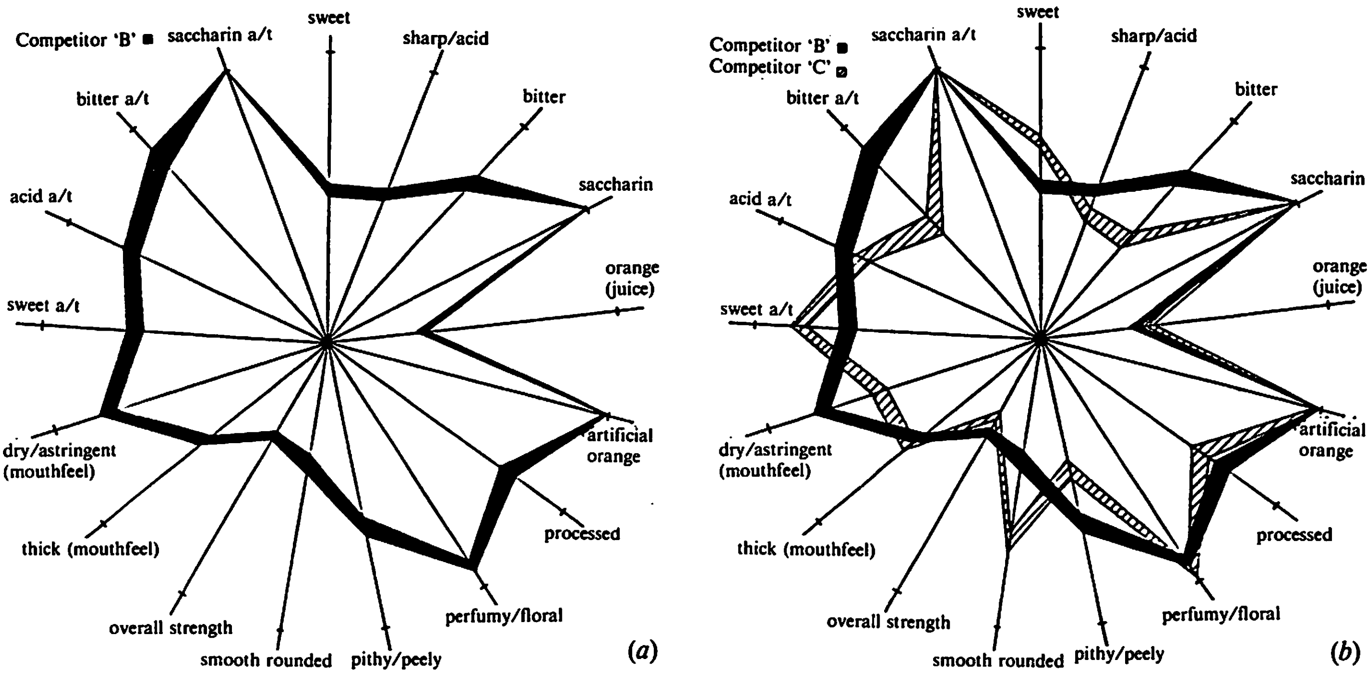

Fig 1 Examples of sensory analysis profiles stars for: (a) a single sample of orange juice; (b) two juice samples superimposed so that the differences in quality note can be clearly seen

determine the fibrousness of asparagus spears. Puncture testers are used in fruit growing countries to determine the degree of ripeness of pears and peaches prior to harvesting.

Apart from these examples, instruments to assess texture in the field are not widely used and judgements are often made by squeezing produce between fingers and thumb. Good fieldsmen can determine the texture and maturity of peas for processing in this way because peas toughen as they mature. Fruits on the other hand soften as they mature but, in both instances, it is important that crops are harvested at optimum maturity for textural characteristics.

It is in the mouth that texture is usually most appreciated. Celery is expected to be crisp and tender, apples are expected to be crisp but in a different way, peas are expected to have substance to their cotyledons but the skins must not be tough and certainly not stick between the teeth. Sweet corn must be milky and neither watery nor doughy. Every fruit and vegetable has its peak of textural perfection and nearly always it is related to maturity. Processing and cooking in the home, of course, will affect texture and often the extent of this effect is noted and the harvesting time modified to account for it. Thus, gooseberries are harvested full size but definitely underripe for canning because they must withstand the scarifying process which tops and tails them.

Size

Today, small is often considered beautiful especially in processed products. Thus there is a tendency for us to prefer petits pois peas, button sprouts, baby carrots, new potatoes and sometimes small seeded broad beans. To obtain such small units in produce needs careful control of the agricultural production of the crops. Intially, cultivar selection is of paramount importance especially in peas and broad beans. Relatively close spacing of plants in the field will ensure that root crops such as carrots and potatoes produce small units and it will similarly affect Brassica crops. In carrots in particular, seed bed preparation and uniformity of sowing depth which affects emergence will also influence uniformity of root size. Other factors of importance are soil type, nutrition and weed control.

The two aspects of size are the actual size of the individual units in a pack and the uniformity of size within a single pack or product. Size can be measured by length, circumference, diameter, width, weight and volume. The contribution to the measurement of quality can assume great importance in some standards and yet be relatively insignificant in others. It can only be assumed that there is a great divergence of opinion as to the importance of size.

Defects

In this category comes those aspects of quality which are of greatest interest to members of this Institution. Unlike size, here is an item of immense importance to the agricultural and food industries. The whole subject of defects can be sub-divided into the different causal agents thus:

1. biological factors
   (a) animal pests
   (b) pathogens

2. enviromental factors
   (a) climate and weather
   (b) soil
   (c) water supply

3. physiological factors
   (a) physiological disorders
   (b) nutritional imbalance
   (c) maturity

4. genetic aberrations

5. extraneous matter
   (a) from the growing medium
   (b) vegetable matter
   (c) chemical compounds

6. mechanical damage

The ravages of pests and diseases are always with us and there is a wide range of agrochemicals available to control most of these. However, even the most dedicated spray programme is unable to provide one hundred percent protection and we see many effects of insect pests and fungal attacks. Carrot fly is a major pest and cavity spot, once the major defect of processing carrots cannot be totally controlled in the field. *Alternaria* cause black specks on Brussels sprouts, scab occurs on apples, *Botrytis* is sometime rife in soft fruit and vegetables and beetles, wasps, aphids, weevils, caterpillars and slugs turn up from time to time in the foods we eat, sometimes even when they have been processed. They are important because if they reach the consumer they can be distasteful and result in consumer complaints. Even worse they can impair the image of the product which may not be recovered so easily as it is lost.

The environment is an important factor as a cause of defects. Climate and weather can result in problems such as wind rub in green beans – a major problem in areas where beans are grown on exposed and windy sites. As the growing bean pods are rubbed against stalks and leaves so the surface tissues are damaged and a brown unsightly scab grows over the affected area. It can be easily removed with the finger nail and may be reduced during the freezing operation but it never disappears completely once present. Carrots which are stored in situ over winter must be protected with soil or straw or both otherwise frost penetrating to the crowns will cause the roots to rot. Corn cobs may be incompletely filled if poor weather prevents adequate fertilization of the silks. Soil conditions may also cause defects, for example, clayburn on carrots which is the result of asphyxiation of the surface cells of the growing roots and causes blue-black patches. An important problem in potatoes for canning, and unfortunately called "wart" disease, is a form of mechanical damage caused by stones puncturing the surface cells of the growing tubers. The cells callous at the point of rupture and a small hard knot of tissue is formed. When the tuber is peeled the surrounding skin is removed and the "wart" which is now brown protrudes from the surface and is most unsightly. It can be easily lifted off the surface of the tuber with a pin but of course this cannot be done commercially and the defect is a major cause of concern to the canner. The availability of water or the inconsistency of its supply can also cause problems in many crops. An absence of water followed by an adequate supply may cause cracking in cherries, tomatoes and top fruits such as pears and it may be the cause of stone gum in plums. The weather is fickle in its supply of water and the obvious answer is carefully controlled irrigation but this might not always be cost effective. Nevertheless, ways of improving the uniformity of water supply to sensitive crops could be advantageous to both grower and the markets he supplies.

Physiological disorder is a good all-round term which can be conveniently and universally applied to those defects where the causes are unknown! Over the years the term has been used for many defects where once the causes have been discovered the defect can be transferred to another category. Shadow and cavity spot in carrots were classified as such until their true causes were discovered. Remaining in this category is internal browning of Brussels sprouts and blond peas. Internal browning can be a major problem not only because the reason why it occurs is not fully understood but also to test for it is destructive. Blond peas, on the other hand, occur mainly where pods are shaded at the base of the vine in years of heavy haulm growth. Nutritional imbalance occurs in many crops and may be associated with absence of minor elements. For example, shadow in carrots can be reduced with applications of boron. Bitter pit in apples is associated with low calcium and this element may also be a factor in the internal browning problem in Brussels sprouts. The effects of maturity as a contributor to defects is questionable because these problems are really associated with other quality characteristics such as colour, texture and even flavour. For example, yellow leaves on the outside of overmature Brussels sprouts and the development of fibre in bean pods as they mature.

Some genetical changes in plants will impair the suitability of the product for the intended market. It is, of course, always important to get the variety right and this is more important in broad beans than in most crops for canning. An unsuitable variety can give dirty brown beans totally unacceptable to the UK consumer and indeed crops of the correct varieties must be rogued so that individual seeds of rogue plants do not get into the pack. To a lesser extent, this consideration is true of other crops such as carrots.

The extraneous matter category is an extremely important one and refers to defects which are present but alien to the product. Perhaps the most serious are those which result from the growing medium. Of great significance today is the importance of stone removal from products during processing or preparation for the fresh market. It is always surprising to recognise that pea beans produced in North America and graded and inspected to State or Federal standards are actually permitted to have stones in them. These cause great problems to canners of beans in tomato sauce because the stones have to be removed on the production line. Vining pea crops are now harvested in the UK with pod pickers where the machines work so close to the ground that stones became admixed with the vined peas. The stones have to be removed with riffles and a final check is often made by passing frozen peas through electronic sorters. One stone in a pack can result in a major consumer complaint. Soil, sand, grit and casing are all examples of extraneous material from the growing medium. Extraneous vegetable matter may not be so serious unless it comprises toxic berries such as those of black nightshade and potato berries which occur in crops from time to time. More usually the extraneous vegetable matter is from the crop plant comprising leaf pieces, stalks, pods or pod pieces. Whilst poppy heads and thistle buds in peas are innocuous, they are nevertheless unwanted. There is a great opportunity for the agricultural engineer to exploit his ingenuity in the development of equipment which can be used on line for the removal of extraneous matter from food products. Many such machines already exist but the continuing presence of extraneous matter suggests that we still have a long way to go.

Chemical compounds are also found in crops from time to time and indeed additives such as sugar and salt are included in most canned vegetables to enhance the perceived quality of the product. Pesticide residues may be present in very small quantities in some food crops but these are probably of insignificant importance providing growers apply compounds at recommended rates. New laws coming into force will mean that there will be upper limits for pesticide residue levels in food crops growers will have to keep a record of compounds applied to their crops and the rates used. Pesticides must not taint food crops so all new compounds need to be checked for their tainting potential. No additives are present in frozen vegetables such as carrots and sweet corn and no preservatives are added to canned vegetables although some consumers believe that they are. The heat processing of the food in the can is all that is necessary to give commercial sterility to the contents.

Finally, mechanical damage is a major category with many ramifications. In simple terms it is the physical impact of the marketable portion of the crop with any object which will damage the plant tissues. But because many of the products are now prepacked fresh or packed processed then mechanical damage can also relate to the condition of the final product. The simplest examples are the cuts, bruises, scrapes, scuffs and crushing which occur on so many crops. Brussels sprouts may be scalped, potatoes suffer a great deal of mechanical damage which reveals itself as brown or black blemishes, carrots bruise and break very easily, all fruits bruise readily and the list of similar damage is extremely long. There is also consequent damage in some instances for example, when immature peas are vined, skins will be split and this can cause wastage. Even if peas with split skins persist to the final pack they may be defective for cuts and, in some cases, grit can lodge under the skin and cause discoloration. Similar damage to broad beans during vining will cause severe discoloration due to complicated biochemical changes within the plant tissues.

Time and space does not permit a full survey of the many aspects of mechanical damage but it is important to realise that such damage can occur in the field before the crop is harvested, during the harvesting operation, handling and transportation to the packhouse or processing factory, during delays, prepacking and distribution, or factory handling and processing (for example during blanching and freezing), during post process handling, warehousing, distribution to retail outlets and within retail stores. It behoves all those who use mechanical implements and machinery to maintain them well, use them at their optimum settings and not over and under load the equipment with produce.

Conclusions

Quality of agricultural products comprises many individual aspects all of which must be at optimum performance in the attempt to achieve perfection. Of course, perfection is never reached, but it is a goal which is constantly there to be sought. It is never reached because the effects of economics and cost also play a vital role in getting products to the retail outlets for display to potential consumers. Nevertheless, quality is becoming more important day by day, more attention is being given to it, more and more often we seek to understand what it is, how we can achieve high quality and what are those factors which will prevent us from doing so. It is also important that we understand what the consumer wants. Will she, for example, be willing to accept products with defects because they have been produced organically? Will she eventually believe that products with defects are of better quality than those which are defect free? The understanding of quality in the future could well become confusing and even confound many of us but one thing it will always remain and that is – exciting.

Pressures for change generate engineering opportunities

Discussion at the 1986 Annual Convention

Lord Selbourne's opening remarks

Agriculture is entering a period of change with farmers having pressure from the animal welfare lobby, the environment lobby, changes in consumer diet and changes in retail outlet requirements. These pressures are coming from outside the industry, but from within the industry itself there are additional pressures from the market place as it loses support, a reduction of costs and the need to add value to the crop on the farm. There will also be a need to open new markets, perhaps outwith the farming industry.

Change is also being generated by advances in science and technology which results in new systems and understandings of crop and animal production.

Questions following Paper 1 (J C Bowman — Environmental and governmental pressure on agriculture)

Dr B D Witney (Edinburgh School of Agriculture)

Q The public's perception of agriculture, largely based on the procedures of 30 years ago is incompatible with modern farming techniques. Are there greater opportunities for the creation of Countryside Parks? These have the advantage of open access, as well as taking land out of maximum production but retaining it as a national resource.

A *I have mixed views regarding Countryside Parks. They must be attractive and accessible to the urban population. Furthermore they must convey what is actually involved in modern agriculture and not be museums. The Parks must show what are the necessary inputs to produce food at a price the public is prepared to pay.*

Dr S A C Larkin (Silsoe College)

Q One of the environmental effects of farming omitted in the speaker's paper concerned that on wildlife and their habitats. For example, drainage and the ploughing of old pastures could be detrimental to wildlife.

A *Because of the widespread use of land for agriculture we are forced to amalgamate many aspect of other uses with it. In future, perhaps 10% of land should be set aside for wildlife conservation and recreational use.*

Questions following Paper 2 (J M Randall — Improvements in animal welfare)

J Moffitt (Hunday Products)

Q When there are pressures on us as farmers, we *do* take notice. But where do we go with regard to the improvement of the environment for laying birds?

A *Legislation exists in many countries. In the UK we have recommendations relating to space requirements for laying birds. There is also a lot of research being undertaken into the alternatives to cages. An interesting finding at Gleadthorpe Experimental Husbandry Farm is that the alternatives seem to introduce other problems. So far there are insufficient alternatives – further research to determine the pros and cons of different systems is necessary before legislation will be possible. The Farm Welfare Council has published a good summary on the subject.*

J Shirtcliffe (Ryecotewood College)

Q Can large livestock farmers afford the changes proposed by the animal welfare lobby?

A *In general, most of the welfare improvements correlate with better husbandry practice and hence improved profitability, eg avoiding the housing of sows on concrete floors. Therefore, it is to the advantage of producers' profits as well as to the animals to follow welfare proposals.*

Lord Selbourne

Comment. We must ensure that irrational demands from sections of the public are firmly rebutted. Scientists must somehow define what is *discomfiture* in livestock, scientific knowledge on the causes of stress in animals is acquiring more and more understanding which will eventually assist in solving many of the problems raised by the current welfare debate.

Professor R J Godwin (Silsoe College)

Q How can we ensure that architects and designers of farm buildings seek out and take notice of research results.

A *An important point! Conferences like this help. Researchers must ensure that their findings are brought out into the open and work closely with animal welfare organisations.*

Questions following Paper 3 (D Arthey — Quality of agricultural products)

B Legg (NIAE)

Q Quality is important for the successful marketing of agricultural and horticultural produce. How much should we be prepared to spend on automatic development of automatic quality grading equipment?

A *The consumer uses his eyes to assess quality in the first instance, so colour sensors must be used to detect and then operate equipment to remove unwanted material. Flavour evaluation is the next step that has to be taken but will be a major problem to measure instrumentally and non-destructively.*

J Moffitt (Hunday Products)

Q Do female taste-buds differ from male ones?

A *I don't know? The tasting panel has a male supervisor. Certainly the girls work well together, and produce consistent results, although interestingly their work seems to be better in the mornings.*

Lord Selbourne

Comment. How can engineers respond to the requirements when we don't know what flavour is?

J Lake (NIAE)

Q Quality is often maintained by using chemicals; for example lettuce can be sprayed up to 17 times before reaching the consumer — will the consumer continue to tolerate this level of pesticide application?

A *At the moment, pesticides are required for the marketing of quality produce. If, in the future, consumer demand for chemically treated crops declines, then alternative pesticide controls, eg some forms of biological control, will become more economically viable.*

Presidential Address (J Matthews — The introduction of new technologies)

Following this paper, a panel of all four speakers was convened for a general discussion.

S Leckie (AEA)

Q How can we get the principles of modelling across to industry more efficiently?

J Matthews. *This has indeed been a problem in agricultural engineering but things are now improving. The biological variability of plants and soils has made it more difficult. The movement of a blade through soil is, for example, more complex than that of a wing through air. The power of the computer is helping in this field.*

C Boswell (HSE)

Q Developments in engineering in the past have focused on benefits to mankind rather than animals. Should we not consider improvement of the working environment for the farmer, farm worker and the general public?

J Matthews *I accept that what the questioner stated is true, but time prevented me from mentioning it in the paper. For instance, providing pure air in a piggery improves the lot of the stockman as well as the stock.*

J M Randall *My paper has a section sub-titled "aids to the stockman" but time precluded me mentioning this during the presentation.*

H Carnall (RAC)

Q I have found that a marquee for lambing is better than a blown-up polythene structure.

J M Randall *The polythene buildings mentioned are permanent, and not blown-up. It is a matter of engineering different solutions to the main problems.*

Lord Selbourne

Q The agricultural engineer has reduced labour input and costs on farms but today we are seeking rural employment. Could not adding value to farm produce be a way forward for engineers to develop equipment to increase rural employment?

J Matthews *There are still some areas where mechanisation may further reduce rural employment such as robotic milking. The only way to increase rural employment is to establish more of the peripheral industries to agriculture in the countryside and perhaps some totally different industries.*

J M Randall *Most current changes made by agricultural engineering developments improve conditions and simplify workers tasks. These will not increase the number of jobs available.*

D Arthey *Food processing may seem to offer some scope initially but, although labour intensive, it is seasonal and the introduction of electronics and microprocessors is significantly reducing the labour requirement.*

Some experiences with the NAC–V eyemark recorder during agricultural selection tasks

D H A Zegers

Introduction

The export market for agricultural products, such as seed potatoes, demands a quality standard which can be maintained at a consistently high level. Quality control takes place regularly during the cultivation and processing of agricultural products. These selection activities are carried out not only in the fields, but also in the premises where the processing takes place. In the field, exposure to the natural (weather) conditions can make it much more difficult to carry out the task properly. Indoors, selection can be carried out unaffected by weather conditions, as environmental factors there are more or less controllable. Furthermore, the use of aids can simplify the task. Selection performance can be expressed as the number of detected departures from standard in the selected batch, varying from fair (50%) to reasonable good (85%). Higher scores are the exception rather than the rule.

Selection has to be considered as an information-processing activity: data are recorded for the incoming batch of products and compared with the information stored in the memory. When individual products do not meet the stipulated norms, they are withdrawn from the 'flow of products'.

In order to obtain insight into the process of information recording (visual perception) and information processing (mental loading) during agricultural selection tasks, data on the eye movements were collected as a standard for the perceptive load. The NAC–V eyemark recorder was chosen as the measuring device, taking into account that one of the main requirements was that it must be possible to move the head (see fig. 1).

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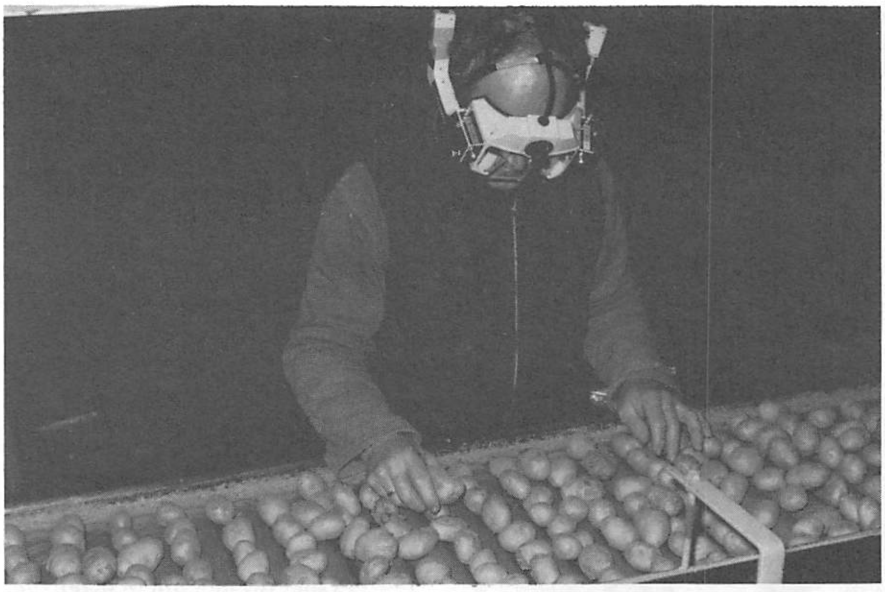
Fig 1 The NAC-V eyemark recorder worn by the author

Eye movement recording by means of the 'corneal reflection' method

The recording of eye movements can provide useful information on whether sufficient time is being allowed for the inspection of a product, in particular, whether a product is being given adequate visual coverage. Eye movements are considered as rotations about a horizontal axis, an axis which rotates with the globe about the horizontal, and a torsional axis along the angle of gaze. Different types of eye movements can be distinguished, such as saccadic, pursuit, compensatory and vergency (eye) movements. From the point of (industrial) inspection, the most relevant eye movements are the saccadic movements. These saccadic eye movements are the rapid conjugate movements by which we change fixation from one point to another voluntarily. The purpose of the saccadic eye movement system appears to be fixation of the image of the target on the fovea, or high-acuity region of the retina, corresponding to 0.6 to 1 deg of visual angle. During the saccade, the image becomes to blurred that the amount of detail that can be resolved is greatly reduced. There is a minimum delay or refractory period ('fixation') between saccadic eye movements of 100 to 200 ms.

During the fixation period, information about the image of the target can be taken up.

The so-called primary picture (image) is obtained by means of the field-lens placed above the nose of the test subject. It shows the subject's field of version (60° horizontal axis and 45° vertical axis). This image is recorded by the field-camera and then passed to the camera controller as the image signal. The near infra red LED light of the eyemark spotlamp then makes a direct virtual image on the cornea of the eyeball. This virtual image, having been captured by the infra-red reflection mirror is transmitted to the x-axis adjusting mirror and the y-axis adjusting mirror. It then passes through the focus lens on to the reflection mirror, finally being focused on the eyemark camera. It is then transmitted to the camera controller as an image signal. Because of the spherical structure of the eyeball, the virtual image made by the LED lamp on the cornea will move slightly depending on the eye movement of the eyeball. The extent of the change in position of the eyemark is magnified both optically and electronically. If the eye of the test subject now moves with respect to the eyemark recorder, the signal on the primary image will also change. That this occurs is due to the fact that the cornea in this case is used as a concave mirror which does not turn about its own centre point, but is displaced starting from a slight angular movement in accordance with the formula:



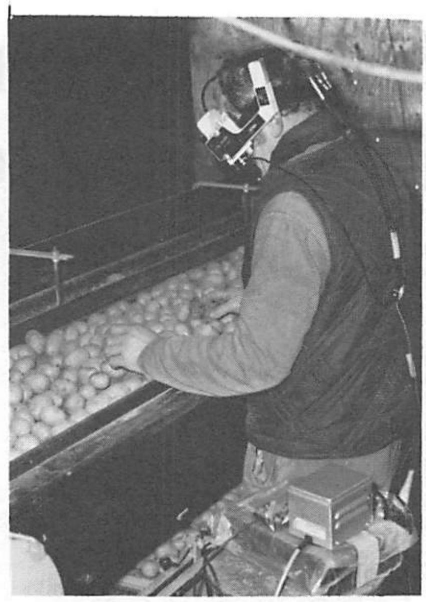


Fig 2 The selecting process with the NAC-V eyemark recorder from the front and the side

$ø = 1.3\,\sigma + 860\,d$

where $ø$ = turning angle of the eye, arc minutes
σ = angle of turn of corneal reflection, arc minutes
d = movement of head, mm

Should the cornea turn about its own centre point, there would be no change in the primary image. With this method, the factor, d, is equal to zero because the priary image also changes with movement of the head.

Practical example

The NAC-V eyemark recorder was used for the selection of seed potatoes (see fig 2). The task is to detect those which do not meet the standard (see fig 3) in the stream of potatoes that passes, and then removing the rejects.

The batch is a known one consisting of good and deviating products in the ratio of 5000 to 200. Three experienced selectors took part in the research as test subjects. A variation in belt speed was included in the test as an extra variable. Their belt speeds, measured from left to right with respect to the subjects were:

I = 6m/min;
II = 8m/min;
III = 10m/min.

As this was only an orientating test, more detailed research has still to be done to find the parameter that best accounts for the eye movements.

The following are possible parameters:

- spatial distribution of the fixation points (fixations);
- number of fixation points (/time unit), average fixation time;
- size and distribution of the saccades.

The data on eye movements are obtained in the following way. A roughly 120 s video recording is made of part of the whole task. By means of a 'video motion-analysing system' such video tapes are then converted into a computer-compatible file. From this, a datafile is made with the following headings; measurement no.; x-posn; y-posn; time; duration of fixation. This chronological array can then be processed further. The video motion-analysing system divides the video image into a matrix of 256 by 256 picture elements (pixels) (65536 positions). Fixation-point positions within 5 pixels are allocated to the same fixation. The sampling period of this system amounts to 40 ms.

The performance in selection is given in table 1, with the number of detected deviations in absolute quantities and as a percentage of the total number of deviations. From this table, it is found that selection performance varies between 64% and 79%. The differences between subjects is slight, and what is striking is the relatively poor performance by all subjects at the highest belt speed.

Test-subject ranking in performance is 1-3-2, subject 2 having the best score.

In analysing the results, the attempt is then made to find an

Fig 3 Overview of some good ("goed") and bad items

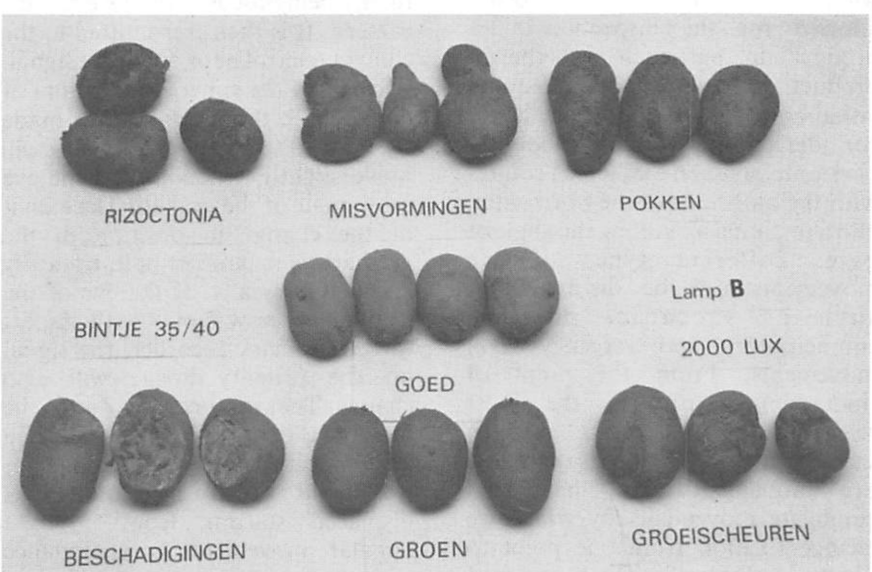


Table 1 Survey of selection performance of three persons at three different belt speeds (in absolute numbers and % of detected deviations)

Test subject	*Selection performance, no (% detection), at 3 belt speeds*		
	I	II	III
1	158 (79.0)	149 (74.5)	136 (68.0)
2	146 (73.0)	148 (74.0)	132 (66.0)
3	151 (75.5)	156 (78.0)	128 (64.0)

Table 2 Survey of the minimum and maximum x and y-co-ordinates of the primary image for the various test subjects at different belt speeds.

Test subject	*Belt speed*	*x and y-co-ordinates of image, pixels*				*Eye movement, pixels*
		x min	*x max*	*y min*	*y max*	*d = (y max − y min)*
1	I	70.0	209.5	20.0	194.0	174.0
	II	66.3	181.3	75.5	188.3	112.8
	III	72.5	185.0	63.0	195.0	132.0
2	I	103.5	201.0	95.0	159.0	64.0
	II	93.5	188.5	87.7	187.0	99.3
	III	103.8	199.5	11.0	177.0	166.0
3	I	65.5	217.0	56.0	197.0	141.0
	II	55.0	188.0	89.4	179.0	89.7
	III	65.5	210.0	72.5	198.0	125.5

explanatory variable that closely accounts for this performance. The different eye-movement parameters give the following picture.

Spatial distribution of the fixation points

The primary image is subdivided into a horizontal x-direction and a vertical y-direction, each 256 pixels in area. The primary image almost covers the entire width of the belt, so that it can be said that the fixations would have to include the whole of the primary image and all the individual products have to be scanned. Table 2 gives a survey of the field within which the fixations have occurred.

From table 2 it is found that only part of the belt has been scanned in the y-direction. Differences in selection performance as the result of the size of the scanned area have not been found.

Number of fixations (/time unit), average fixation time

When deviations from standard in the case of tubers have to be spotted, it can be assumed that there must be a fixation, when such a deviation is at least recognised, and fixation will no doubt also occur because of other signals.

A number of characteristics of these fixations are given in table 3.

From table 3 it is clear that relatively the lowest number of fixations is to be found at the highest belt speed and that the average fixation time at that speed is shorter than at the other two speeds (this is made fairly apparent in table 4). No clearcut line is to be distinguished as to the total number of fixations during the task. What is certain is the fact that the number of fixations for all three test subjects at the highest belt speed is lower than at the other speeds. This probably explains the relatively poor selection performance at this speed. As regards test subjects 1 and 2, it is striking that a positive tendency is evident between fixation time and selection performance.

Ranking for increasing average fixation time is found to be identical with that for selection performance. This means that, as average fixation time increases, selection performance improves likewise.

Table 3 Fixation characteristics

Test subject	*Belt speed*	*Total time of selection, s*	*Average fixation time, ms*	*Number of fixations*
1	I	480	133	3600
	II	360	132	2728
	III	300	122	2459
2	I	440	166	2651
	II	360	129	2791
	III	290	121	2397
3	I	465	126	3941
	II	360	151	2857
	III	305	118	2542

Table 4 Survey of the average fixation times

Test subject	*Fixation times, ms*			
	Belt speed I	II	III	*Average*
1	133	132	122	129
2	166	129	121	139
3	126	151	118	132
Average	141	137	120	132

Size and distribution of the saccades

A last possible explanatory variable can be arrived at from the length of the jerk between two successive fixations (saccade). The average values are given in table 5.

Table 5 Survey of maximum and average length of the saccades

Test subject	*Belt speed*	*Saccade length, pixels*	
		d(max)	*d(mean)*
1	I	143.74	30.91
	II	115.64	30.63
	III	110.74	30.30
	Av	**123.37**	**30.61**
2	I	58.41	15.44
	II	74.97	20.87
	III	120.05	21.61
	Av	**84.48**	**19.31**
3	I	138.57	31.61
	II	113.31	26.92
	III	126.60	33.92
	Av	**126.16**	**30.83**

In table 5, it is obvious that test subject 2 is responsible for notably shorter saccades than the other test subjects.

Conclusions

The NAC-V eyemark recorder was tried out in the selection of seed potatoes to evaluate the practical suitability of such a measuring device for agricultural research as well as to find relevant eye-movement parameters which show a link with the selection performance. The equipment came up to expectations both as regards measuring precision and applicability.

Portability, especially for measurements lasting longer than 15 minutes, leaves a great deal to be desired. Despite head movement being permitted, the subjects made less use of this flexibility with the equipment than without.

With reference to the eye-movement parameters, a number of alternatives can be applied to selection performance. The spatial distribution of the fixation points gives insight into the adopted visual field of the test subjects. The relationship between the number of fixations, the average fixation time and selection performance has been fairly clearly established. It should be noted that as the average fixation time decreases, selection performance deteriorates. It was also observed that the shorter the average length of jerk between successive fixations, or saccade, the more the selection performance improves.

In the follow up research, these relationships (and no doubt others as well) will have to be analysed with greater precision in order to obtain a more reliable picture, but the present test results provide ground for a measure of optimism.

Book Reviews

Dictionary of Mechanical Engineering. 3rd Edition

G H F Nayler

Publisher Butterworths; Borough Green, Sevenoaks, Kent TN15 8PH, 1985. ISBN 0 408 01505 5 £28.00.

THIS book is well laid out and produced. It covers a wide range of subject matter from very elementary machine elements to quite advanced concepts. My initial impression was that it may have fallen between several stools in an attempt to do too much. For example, there are definitions of "handle" and of "principal planes of stress". On a second scan through the dictionary, however, it can be seen to contain much interesting information and even the experienced engineer should find items of interest. The author of such a book has a difficult task in that his audience is a wide one, covering the student, practising engineer and the specialist scientist or engineer. Inevitably, if his book is used by the latter group, not all of his definitions will necessarily meet with approval. On the whole, however, he has maintained a good standard which will prove satisfactory for the practising engineer. There are some examples, however, where he might have made things easier for his readers. For example, the definition of moment of inertia could have been improved by showing its relevance to angular motion, is in the definition of rigidity modulus which is given as a term in a mathematical equation. It would have been much more informative, as well as more fundamental, to have defined it in terms of shear stress divided by shear strain. This would have enabled it to be related to Young's and bulk moduli in a logical manner.

The drawings in the text are clear and illustrate the various topics well. The dictionary had, in earlier editions, concentrated on terms relating to moving parts, machines and the production of power and its adoption in transport and mechanisms. The new edition includes terms pertinent to design and manufacture, including robotics. Some topics are not treated in depth, such as foundary practice, metallurgy, metrology and welding since these are covered by other dictionaries in the Butterworth Technical Dictionary series.

The dictionary can be considered to be a useful addition to an engineer's reference books since it contains terms covering a very wide field. It will prove useful to those working in a number of activities, either in practical or more academic occupations.

MJO'D

Tools for Agriculture

Introduction by Dr I Carruthers

Publisher: Intermediate Technology Publications Limited 9 King Street, London WC2 8HW, 1985. ISBN 0 946688362. £15.00 (paperback)

THE first edition of *Tools for Agriculture* was published in 1973, followed by a second edition in 1976, and this the third in 1985. It is perhaps a pity that the title does not include any mention of the type of equipment other than "appropriate" which is featured. "Appropriate" in this instance is for small-scale farming, and the guide contains information about products and manufacturers from seventy-seven countries worldwide.

There are sections on wool harvesting and bee keeping in addition to the previously featured ten subject areas, which range from seed-bed preparation and sowing, to crop protection, harvesting and transport, and livestock. Each section has an introduction from a specialist in the particular subject, giving a general background to the area of agriculture in which the tools are used. Most of the introductions, which are mainly in a standardised form provide, where appropriate, the pros and cons of using particular implements. This includes cost effectiveness, advice about selection and, most interesting and enlightening, a mention of the impact, both social and otherwise, of adopting particular implement types.

The main part of each section then follows, with detailed description of a wide range of tools, mainly accompanied by line drawings, but also some photographs. The line drawings often show more useful detail than photographs and certainly do not detract from the publication. Brief geographical details of the manufacturer are given with the products, but more information, including telephone and telex numbers, are provided in an alphabetically arranged country and company index. This, together with an equipment index, provides for quick and easy location of the products manufactured by some twelve hundred companies.

Undoubtedly a most useful publication compiled with care and enhanced by the introduction from specialists in the different subject areas. *WCTC*

Soft start for the reduction of starting currents of grain drying fans

A R Kneeshaw

LARGE electrical currents which are produced when starting grain drying fans can lead to expensive, but otherwise unnecessary electricity supply reinforcement when a new drier is to be installed. An alternative to the commonly used star-delta starter is electronic soft start and this article discusses the principles and practice of the use of this equipment.

Introduction

When a new on-farm grain drying installation is to go ahead, the Electricity Board must assess whether the existing electricity supply is adequate for the load, both in terms of running power and starting current. High starting currents can lead to several problems associated with the effects of transient voltage dips and surges.

Invariably, grain drying fans are installed with star-delta starters, the starting current characteristics of these devices being well known by Electricity Board engineers. Electronic soft start has the potential benefit of being able to limit current to a lower level than with star-delta start, but the technique is less widely used and understood.

Recent practical work has been carried out to throw some more light on this subject and it has been found that although swapping a star-delta starter with a soft start can improve the smoothness of start, to get the most benefit from the system in terms of reduction in starting current, the whole starter/motor/fan system has to be taken into consideration and possibly modified. An engineering solution for backward curved centrifugal fans has thus been developed.

What causes large currents during starting?

When a squirrel cage induction motor is

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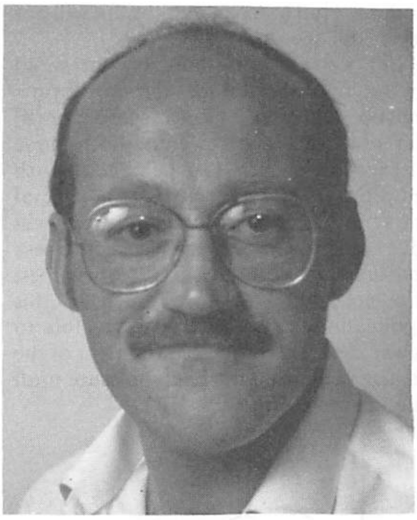


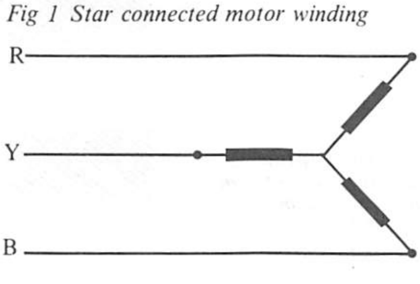
running at full speed, there is an induced back-emf (electro motive force) in the stator windings, which acts as a resistance to current flow. At start, however, the windings have no back-emf and hence, as it is only limited by the winding impedances, current tends to be much larger than normal. Only after acceleration to full speed does the back-emf reach its full amplitude and current return to running level.

Star-delta starting

On farms, star-delta is probably the most common method of starting for three phase induction motors.

As the stator windings of the motor are initially connected in a star configuration (fig 1) they present a higher impedance (x 3) to the 415 volt phase supply voltage than if connected direct on line in the delta or running configuration and hence current is limited (fig 2). After the

Fig 1 Star connected motor winding



motor has built up speed (and back-emf) in the star connected windings, the connections can be switched to delta for final acceleration.

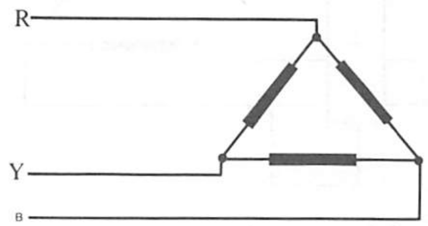


Fig 2 Delta connected motor winding

Electronic soft start

Most electronic soft start circuits use thyristors to apply, initially, brief pulses of current within each voltage cycle to the motor windings (figures 3 and 4). The

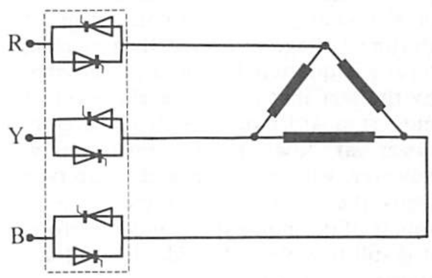
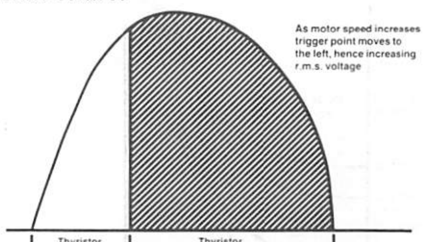


Fig 3 Thyristor layout for a typical 3-phase 3 wire soft start

Fig 4 Example of 1/3 voltage cycle with soft start control



duration of the pulses increases until, at full speed, full voltage is applied. This means that an infinitely variable rms voltage is available from the soft starter.

The way in which the soft start applies

this increase in voltage can be controlled in many ways. The simplest system is a pre-programmed pedestal and ramp where an initial step voltage is applied to start the machine and a ramp voltage accelerates the motor to full speed (fig 5).

This system is not ideal if the intention is to minimise starting currents as the complex interaction of torque requirement and motor impedance will still lead to a non-linear increase in current, the characteristic of which, is difficult to predict.

It is accepted that a current feedback loop is the best solution if current limitation is of prime importance. Here, the current level is monitored by the soft starter and the voltage applied is limited to prevent current rise above the pre-set level (fig 6).

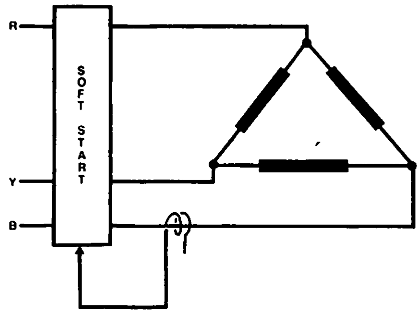
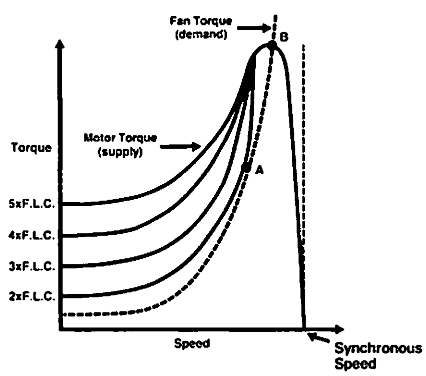


Fig 6 Current feed-back soft start

Limits to the reduction of starting current

The limiting factor to how far voltage and current can be reduced during starting is the torque production capability by the motor. This is proportional to the square of the voltage — in simple terms, if starting voltage is halved then starting torque is quartered. This is exacerbated by the fact that torque development of most standard motors is also inherently lower at low speeds. Fortunately, however, with most fan and pump type loads the work torque increases as a square of the motor speed and, therefore, it is still feasible to consider low voltage starting techniques.

Fig 7 Torque/speed curves for different current unit settings



Note: When Fan torque = Motor torque at A no further power is available to accelerate the fan to the correct operating point B

Fig 5 Pedestal and ramp soft start

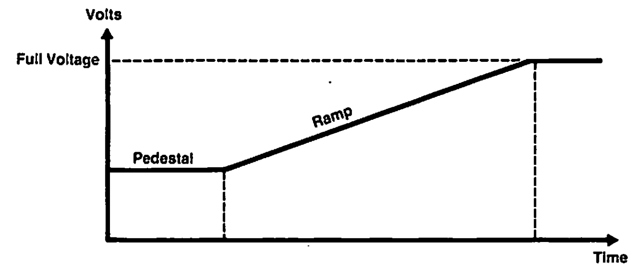


Figure 7 shows what might be typical motor torque curves with current limit soft start. Note the falling off of torque at the lower speeds with lower current limits. Note also the fan load curve — in the case where this curve cuts the motor torque curve (A), motor torque will equal fan load and no further acceleration will take place. In this particular case, it is apparent, therefore, that with currents under 2 x full load current the fan will not reach full speed.

If lower currents than this threshold are required then either (a) motor torque must be increased at lower speeds, or (b) fan load must be lowered. Both these alternatives can be achieved with modifications. In case (a) special induction motors are available which will give higher torques at lower speeds. These motors are commonly used for winches, lifts etc., but can be adapted to this application. In case (b) it is possible to lower the load torque requirement of the fan by increasing the back pressure until the fan stalls (fig 8).

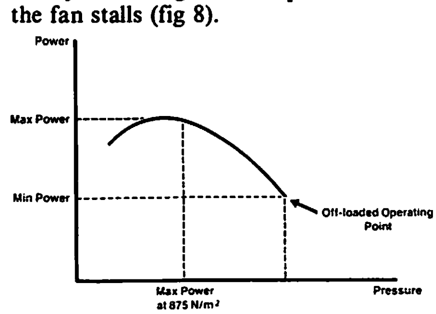


Fig 8 Backward curved centrifugal fan power/pressure curve

From fig 9, improvement from both modifications can be seen as a greater differential between motor torque and fan load at any given speed.

Tests

Tests involving a leading grain drying fan manufacturer have shown that the use of soft start with a high torque motor and inlet blocking can reduce starting currents to as low as 1 x full load current. This compares with transients of over 5 x full load current for star-delta systems. In conclusion, a commercial version of this system has been produced to capitalise on situations where farmers, for starting current reasons, are faced with the costs of reinforcement of electricity supply greater than the additional cost of the soft start alternative.

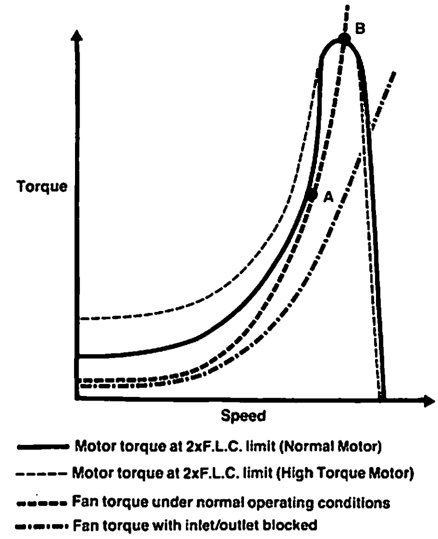


Fig 9 Motor torque curves for normal and high torque motors and farm torque curves for normal and off-loaded operation.

The future

It is likely that in the future, as well as considering the magnitude of voltage drop produced when a motor starts, electricity supply authorities will be taking into account the speed of these voltage changes. Recent attempts have been made to quantify the perceptibility of these 'flicker' voltages for soft start and

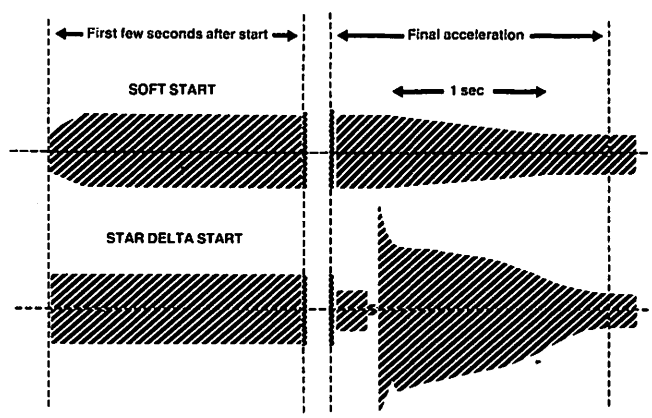


Fig 10 Typical current waveform envelopes during soft and star-delta start

star-delta start and the results show marked benefits when using soft start.

The above diagram gives a visual indication of the differences in the speed of current change (and hence voltage change) between soft start and star-delta start.

The implementation of any resulting regulations regarding 'flicker' voltages will enhance the practical benefits of soft starts and will make their use more common in situations where the necessity for electricity supply reinforcement is being considered.

More sophisticated electronic motor drives are emerging which, as well as providing soft start, give high levels of motor protection, speed control and facilities for running cost reduction by power factor control. The falling price of such controls will inevitably mean that this type of equipment will become commonplace in many applications in industry and agriculture at the expense of traditional electro-mechanical starting equipment.

Tyre performance — a catalogue

G Jahns and H Steinkampf

G Jahns

H Steinkampf

THE overall tractor efficiency, especially if high towing forces are required as for tillage operations, is widely affected by tyre performance. Improved tyre performance therefore means reduced fuel consumption and time saving. The main quantities of tyre performance, characterising the losses between tyres and soil are the coefficients for slip, rolling resistance and traction. These quantities do not only depend on the design of the tyres but also on the operational conditions.

Therefore, performance quantities measured under practical conditions are the basis for the selection of tyres by the farmers and tractor companies as well as for the further development of tyres. They allow, for example, a quantitative comparison of different tyres under equal working conditions.

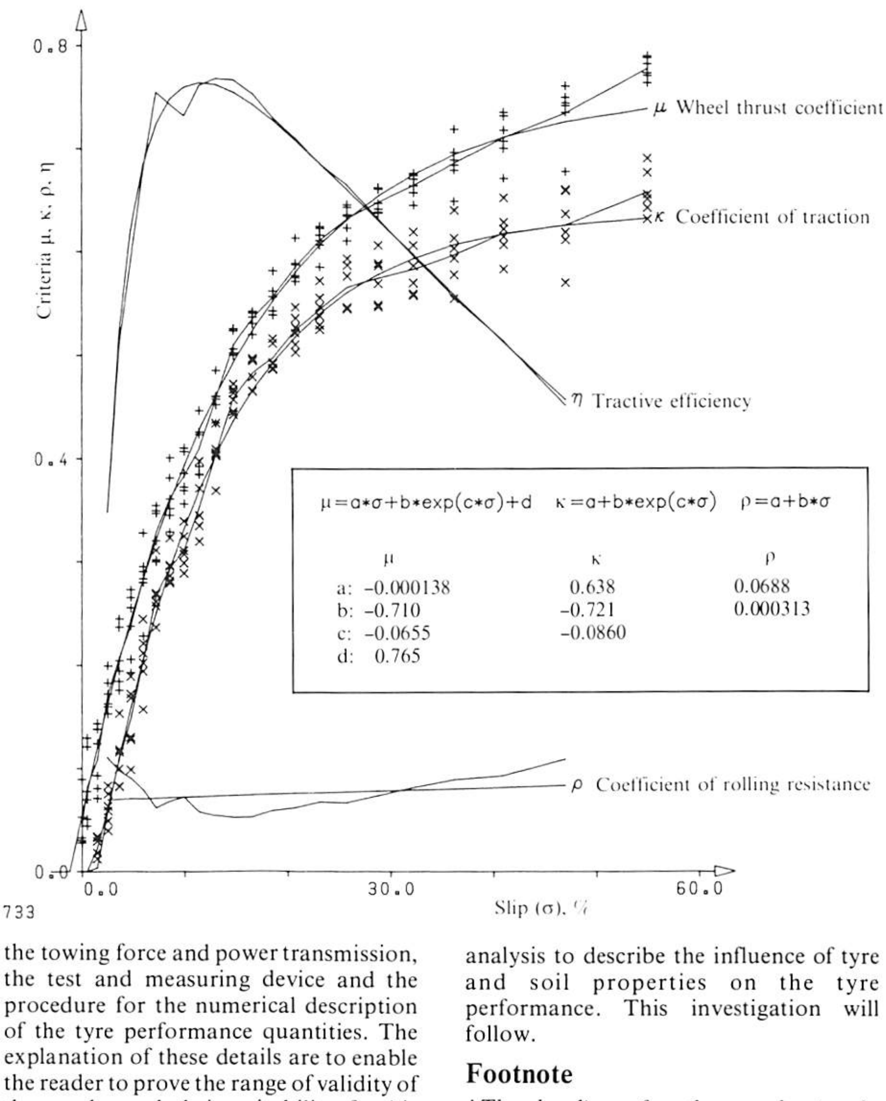
The results of several thousand test runs with different tyres and conditions have been processed for computing, approximated by an equation, systematically sorted and collated as a catalogue. The figure shows the final result of a test consisting of six equal test runs. The catalogue contains about 800 tests.†

As an introduction to the results, a short review is given about the theory of the towing force and power transmission, the test and measuring device and the procedure for the numerical description of the tyre performance quantities. The explanation of these details are to enable the reader to prove the range of validity of the results and their suitability for his special purpose.

Because the basic test data as well as the final results are processed for computing and stored, the requirements are given for using this data in computer simulation and for further quantitative analysis to describe the influence of tyre and soil properties on the tyre performance. This investigation will follow.

Dr Ing Gerhard Jahns is a scientist at the Institute of Basic Research in Agricultural Engineering (Institut für landtechnische Grundlagenforschung) and Dr Ing Heinrich Steinkampf is on the staff at the Institute of Production Engineering (Institut für Betriebstechnik) of the Federal Research Centre of Agriculture (Bundesforschungsanstalt für Landwirtschaft Braunschweig – Völkenrode-FAL), Braunschweig, West Germany.

Tyre size:	20.8/70R38	Rim size:	W16L X 38
Manufacturer:	Pirelli	TM 700:	
Ply rating:	8 PR	Lug height:	100%
Rolling radius:	83.82 cm	No of lugs:	40
		Lug angle:	45 deg
Wheel load:	19.53 kN	Direction of wheel rotation:	forward
Inflation pressure:	1.30 bar	speed:	3.40 km/h
Utilisation:	64.43%		
		Pore space:	41.00–47.70%
Soil type:	sandy silt loam	Soil moisture:	14.30–17.70%
Soil condition:	2 grubbings, t = 17–19cm	Preceding crop:	cereals
Surface condition:	stubble		



Footnote

†The headings for the graphs in the catalogue are translated into 11 languages. The catalogue is available on loan through the Edinburgh School of Agriculture Library, or alternatively reprints of "Special Edition No 80" can be obtained from FAL, price DM 20.