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Golden Jubilee 1938–1988 Review – Part II

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Front cover:
The 'real' Institution crest, showing the sower's seeds and his basket.

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Editorial Note

WE apologise to readers for the delay in the issuing of Journals No 3 and 4 of this current volume, but the postal strike caused delay to No 3 proofs being corrected and returned to the printers. This delay has had a "knock on" effect, which will take a number of issues to clear.

Moreover, no final copy double check was made with Issue No 3 due to the postal strike to avoid the publication date becoming excessively late. Murphy's Law ensured that between galley and final proof stages, the printers dropped 4 lines from the paper: "Fifty years of mechanisation advisory work". The missing lines should be inserted between lines 11 and 12 of the centre column of page 79, following "--- commercial holdings". These read "After the first rush of entries to NAAS, a careful recruitment policy was followed, and it soon became possible to select one or two well ---".

We apologise for any inconvenience to both readers and authors.

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Microcomputer-based automatic monitoring system for beehive temperatures

T G Knowles, R P Heath, D J Iley and A T Vranch

Summary

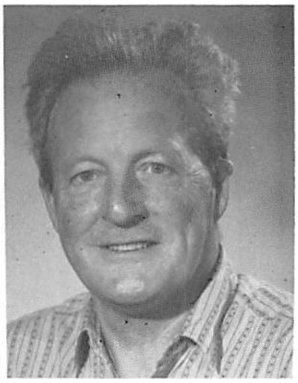
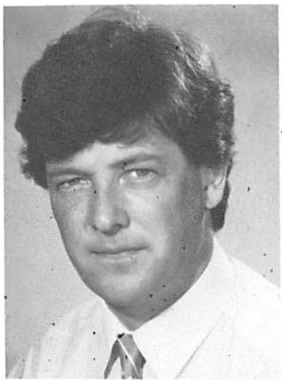
THE aim of the project was to gain knowledge about the system design necessary to measure temperature in a beehive. The data was to be obtained automatically and remotely with the benefit of real time file identification. It also needed to be inexpensive, reliable, accurate to 0.5%C and to retain a normal situation within the hive.

Investigations to determine the relationship between temperature and activity in a beehive are intended to eliminate much of the usual seasonal physical manipulation of the colony with its inherent disturbance and the loss of production. The system could then be readily applied to any other system which would benefit from remote sensing.

The system made use of a ZX Spectrum microcomputer and peripherals which enabled the capture and processing of temperatures, measured by devices which gave a signal output proportional to ambient temperature (PTAT) in the hive. A 200 m land line was used to connect the hive with the computation facility which was housed indoors to avoid problems of security and integrity of system. Signals received were stored on a Spectrum microdrive tape and subsequently down loaded to a PDP 11 computer for mass storage and statistical analysis. The results showed temperature profiles in the hive and the potential for 3D graphical representation with an opportunity, through file addressing, of cross correlating to ambient conditions.


Toby Knowles *Richard Heath*

David Iley *Adrian Vranch*

1 Introduction

Colony temperature control by honey bees (*Apis mellifera*) is fundamental to their lifestyle especially their ability to overwinter as a colony. Brood (non-adults), clustered bees and food supply in use and stored have different temperatures depending upon the activity of adult or juvenile bees. Remotely sensed temperature profiles give the centre and rate of activity which may be used as a management tool for beekeepers. Automatic recovery and processing of inhive data revealed an invaluable tool for normal management practices of beekeepers and it may be used to map and cross correlate bee activity to ambient conditions and hive designs. Currently a number of different hive designs are in use, labour involvement can be high and swarms and loss of honey production arise from physical mismanagement of colonies.

A number of authors have worked on temperature measurement with honey bee colonies in adverse climatic conditions. Varieties of method have been used to read temperatures ranging from mercury thermometers (Nunez, 1979) and thermisters (Szabo, 1985) to thermocouples (Minnick, Murphy, 1976). No evidence could be found in previous work of employing the more modern and reliable PTAT transducer sensors used in this work. PTAT transducer sensors display distinct advantages over other sensors in that they are small in size, can be remotely sensed, act as a high impedence, constant current proportional to temperature device, need no elaborate support circuitry and work off a low voltage supply.

All previous methods relied on manual collection of data or some manual data transfer for analysis after

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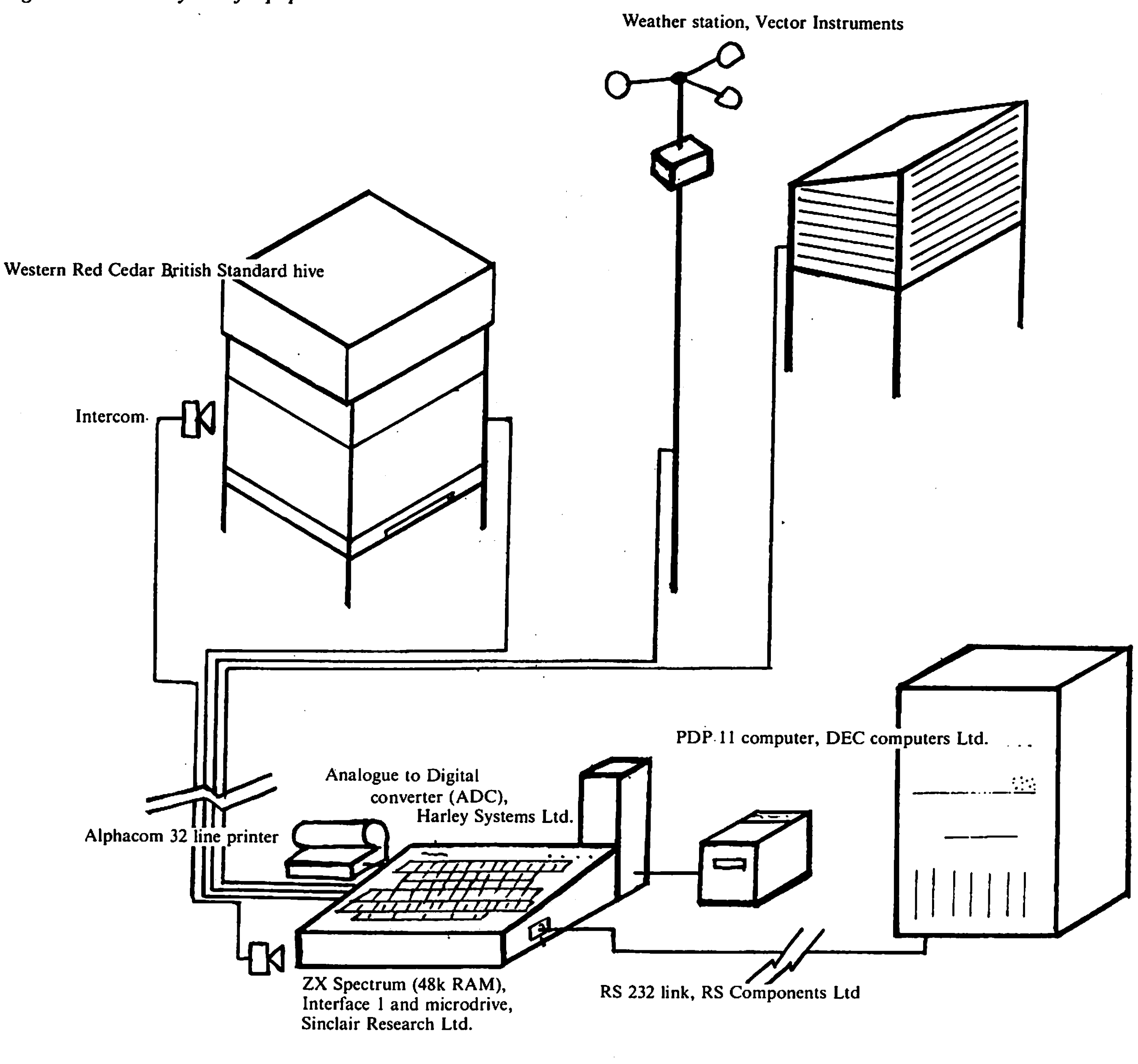
Refereed paper.

capture. The purpose of this approach was to automate the data collection, storage, transfer for analysis and processing for interpretation. Hives with low numbers of frames, observation hives or bee houses or a combination were used by previous workers. Notable exceptions to this were the Agricultural Research Service (1971), and Agriculture Canada Research station (Szabo, 1985), using, respectively, Langstroth brood boxes three tiers high in Wisconsin, USA, and Langstroth double brood boxes. Both these investigated typical conditions in those areas of the world and portray behaviour in normal colonies. More recently comparisons have been made between plastic and wooden hives (Möbus, 1986) and remote, continuous sensing work has been undertaken (Mapp, 1986).

2 Materials and method

The general layout of the hive, data recording equipment and weather station are given in figure 1. The Harley system ADC 12.8, a 12 bit, 8 channel analogue to digital converter (ADC) was used with the ZX Spectrum. Its 8 inputs were bounded by a 5 V stablilised output and a 9 V nominal output used to energise the PTAT transducers. The PTAT transducer signals, generated as a current to minimise losses, were transmitted over 200 m of landline to be converted by 8 cermet multiturn trimmed 10 kohm resistors with a 0 to 3 V range. Noise reduction was aided by 0.1 μF capacitors in each channel and potting compound used on junctions at source. The PTAT transducers pass 1 μA/K and are trimmed to 298.2 + or − 2.5 μA at 298.2 K and generate a linear response to temperature change (RS Components Ltd, 1983). As the highest readable temperature was 40°C, a resolution of 13.107/K with the 12 bit (4096 step) ADC was achieved. To fix two temperature points and to calibrate the system, a calorimetry thermometer, operated in the 24°C to 30°C range, accurate to 0.1°C and readable to 0.01°C, was used in a well insulated container with hot liquids and again with an ice/water mix. Many readings per sensor were taken to fix the necessary two points. An accuracy to ± 0.2°C over the 24.5°C to 29.5°C range was shown: an accuracy of ± 0.2°C over the 0°C to 24.5°C range was anticipated. An intercom was used to manually associate calorimetry thermometer readings with the ADC output to the computer through a calibration routine written in the program.

Fig 1 Schematic layout of equipment



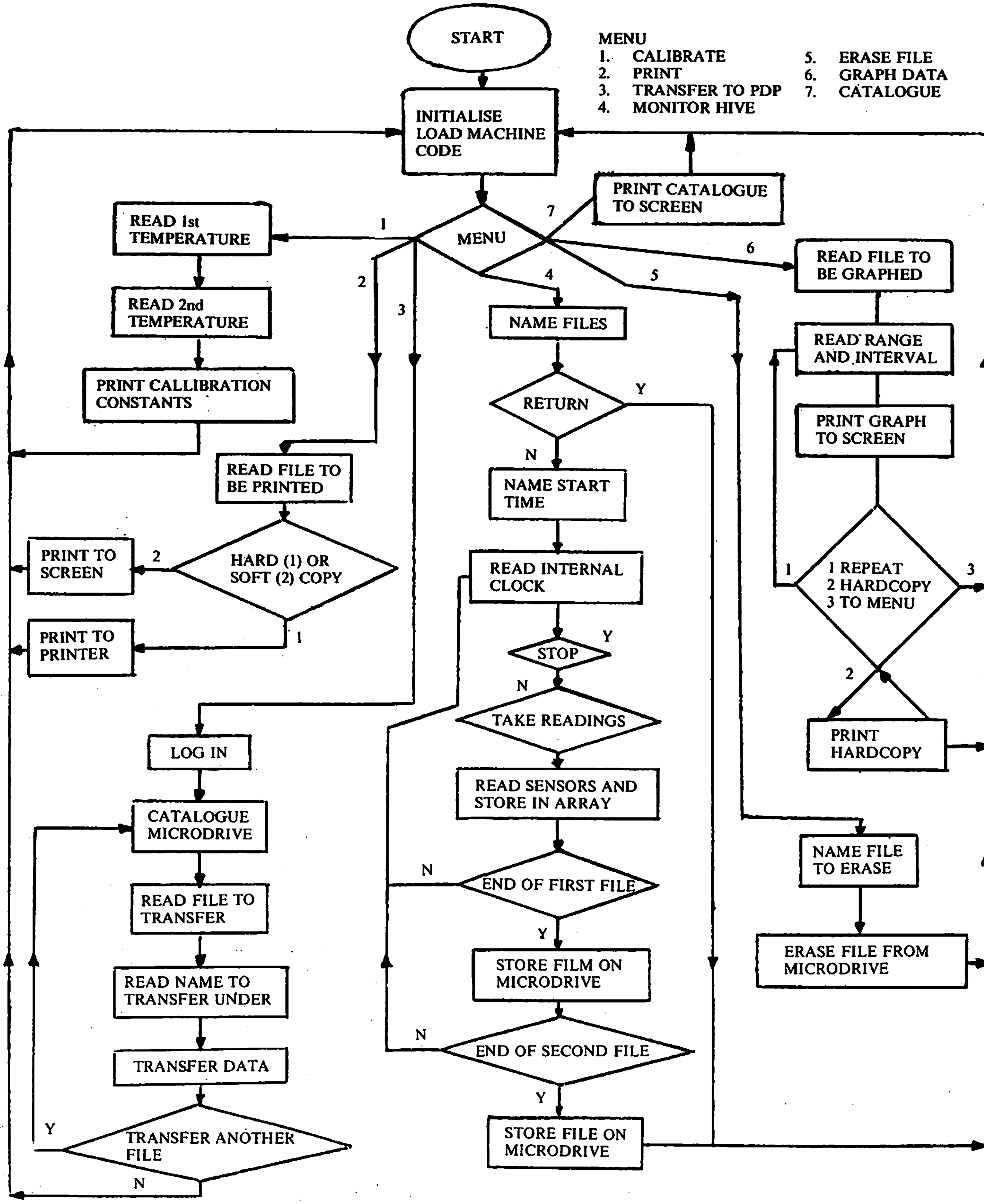


Fig 2 Software flow chart

Note: In figures 4–16 inclusive the titular coding is explained by taking fig 4 as an example, viz: free 860319 – 1986, third month (March), 19th day. Readings 1–49 = the range was taken from the whole day (a potential reading every half hour whereby 1 = 00.00 h). Interval 9 results in a set of readings at the half hours numbered 1, 10, 19, 28, 37, 46.

Trials were conducted to determine the best overall size, shape and positioning of the sensors in the comb. The dimensions of the potting compound mount was such that the sensor could be entered into the comb from one side and the transducer face fitted flush with the working face (outer surface of the comb). Vaseline was used to mask the transducer face as it is a material upon which bees will not deposit propylis (a gummy plant residue) not wax and itself not buffer the temperature significantly. The wires travelled up the non-working face of the comb and were stapled to the top bar. Little peripheral cell damage was caused and the bees did not avoid the cells in the proximity of the wire.

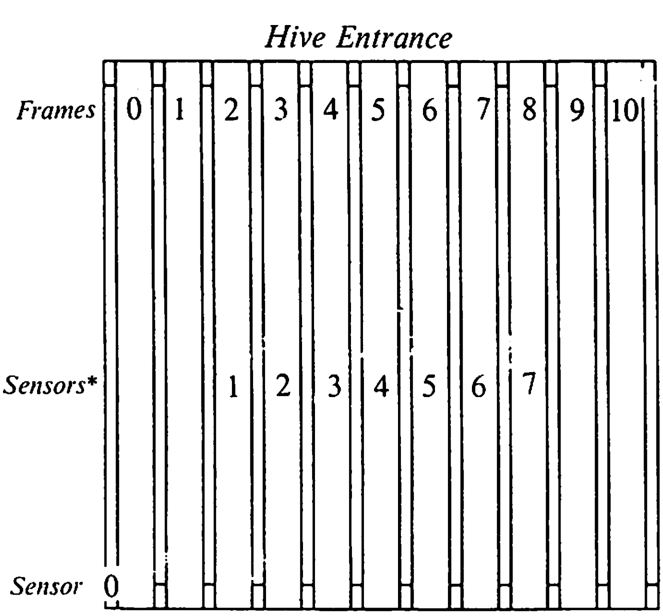
Initially experiments were centred on fitting each of the sensors into one comb cell only. The sensor diameter (6.5 mm) defeated this objective as worker cells are 5mm in diameter.

An automatic weather station 50 m to the east of the hive recorded air and soil temperature, relative humidity (RH), rainfall, windspeed and direction, sunshine hours and leaf wetness. These data were transferred directly to the PDP computer. A PTAT transducer sensor in the top NE corner of the hive recorded unclustered hive temperature.

The aim was to take temperature and time readings for later cross referencing with Meteorological data. The ZX Spectrum does not have a clock, but memory locations may be used to "count" time since the computer was activated on a base of the mains electricity 50 Hz frequency. A machine code routine read each sensor 300 times at every half hour period and computed an average which was then stored in an array. A delay between reading different sensors prevented line cross-talk. A 50 x 8 array was used to store 49 sets of data over 24 hours. When complete the data were transferred to microdrive. Capture, cataloguing, erasing, printing (characters and graphics) and transfer of data were provided from menu (figure 2).

The graphical output had time on an inclined axis to simulate the three dimensional view (figure 4). This axis can be manually incremented according to the number

Fig 3



**The sensing surfaces are flush with the right hand side of combs*

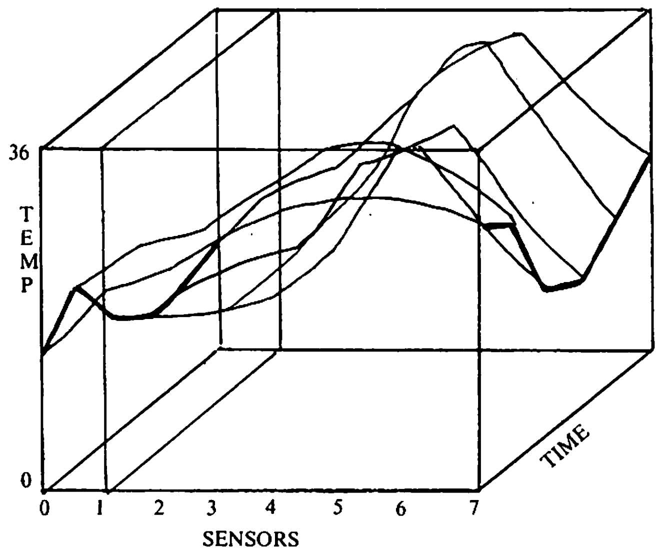
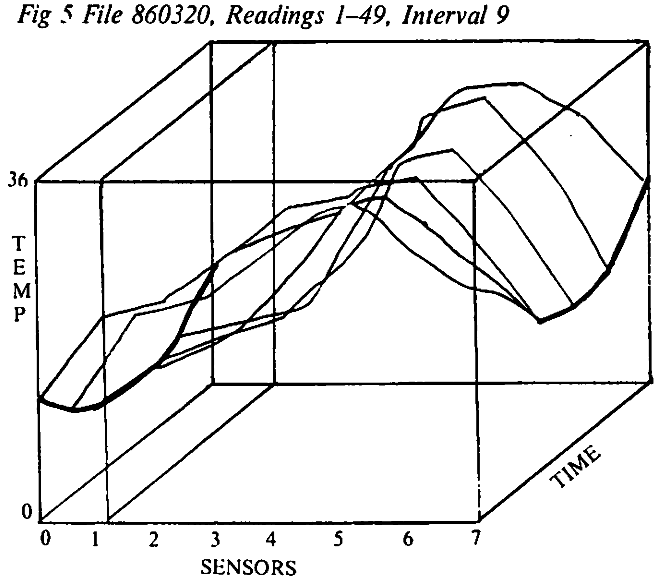


Fig 4 File 860319, Readings 1–49, Interval 9

Fig 5 File 860320, Readings 1–49, Interval 9



and range of readings required from the stored time period of the tape file. The hive position of the sensors occupies the horizontal axis with temperature the vertical. The amibient hive temperature sensor was isolated from the frame sensors by a box drawn at the zero sensor position.

3 Results

Seven of the 11 frames were covered with bees when the hive was opened on 19 March, 1986 for sensor installation. The schematic arrangement of combs and sensors relative positions is shown in figure 3. Installation of the sensors took about an hour in total, following which the system was run for four days and the captured data is shown in figures 4 to 14. To add clarity, the outside edges of the computer generated graphs were inked in by the program. It can be seen by the readings from sensor 0, in the top north east corner of the brood box, that there was little difference in the peripheral temperatures in the hive between the four days. Sensors 1 to 7 were on the central combs and show temperature fluctuations over the four days with the greatest fluctuation in the first 24 hours. The results agree with the findings of the US Agriculture Research Service (1971), where three days following manipulation were required for colonies to

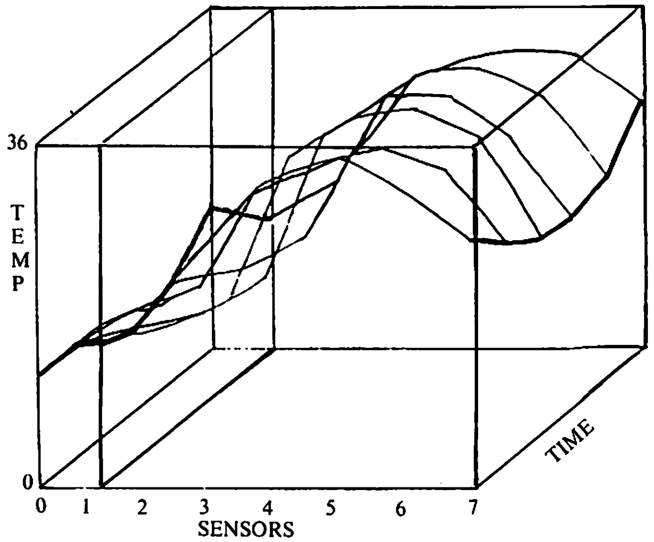


Fig 6 File 860321, Readings 1-49, Interval 9

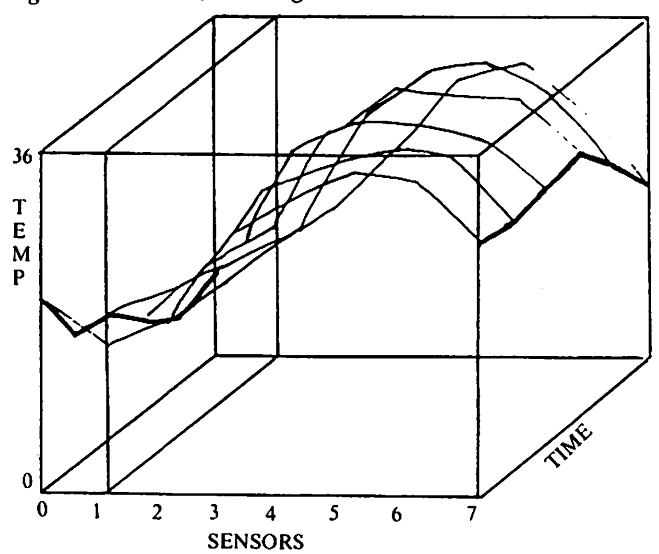
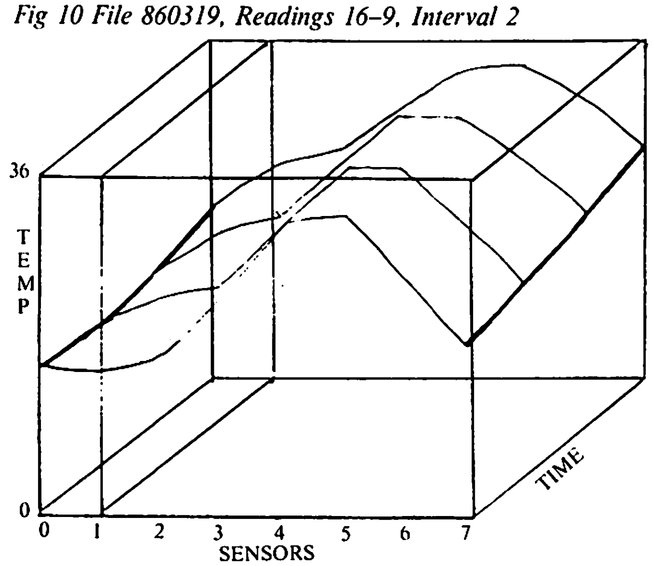


Fig 7 File 860322, Readings 1-49, Interval 9

regain quiescence. This points in favour of management techniques which do not disturb the brood nest.

Lines may merge, figure 9 (1725 to 2055 data) and then be clarified by time axis reversal shown as figure 10. The flatter profile in figure 8 arises from "shaking" the bees during manipulation. The high value of sensor 0 readings is due to solar gain during manipulation for sensor

Fig 10 File 860319, Readings 16-9, Interval 2



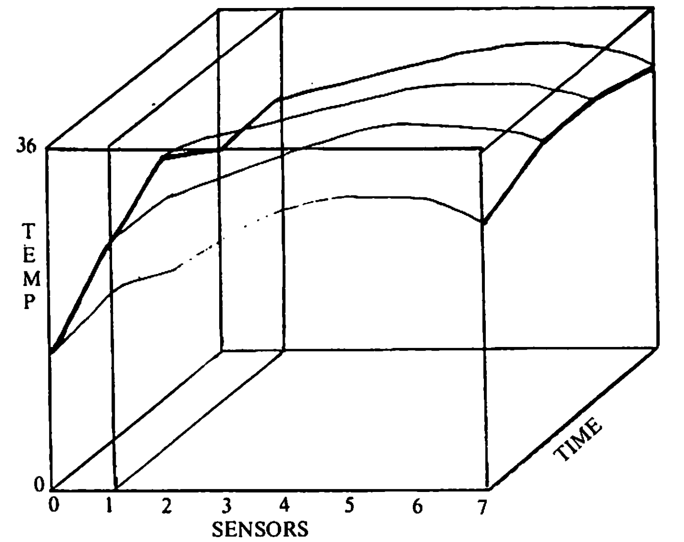


Fig 8 File 860319, Readings 1-8, Interval 2

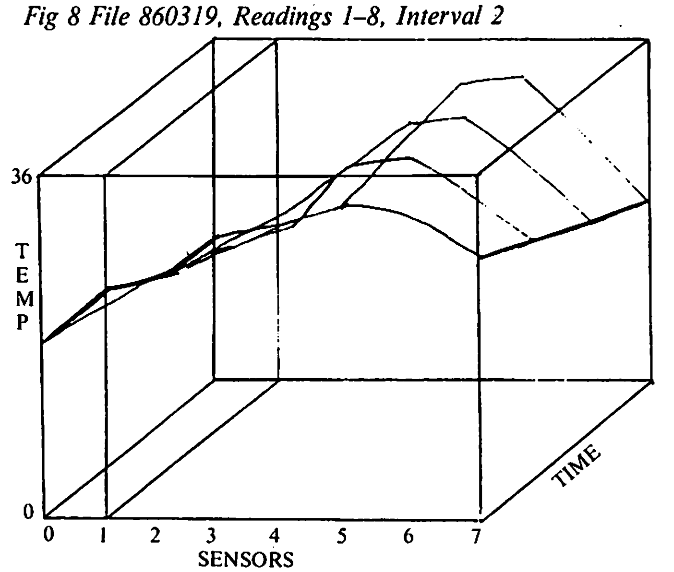
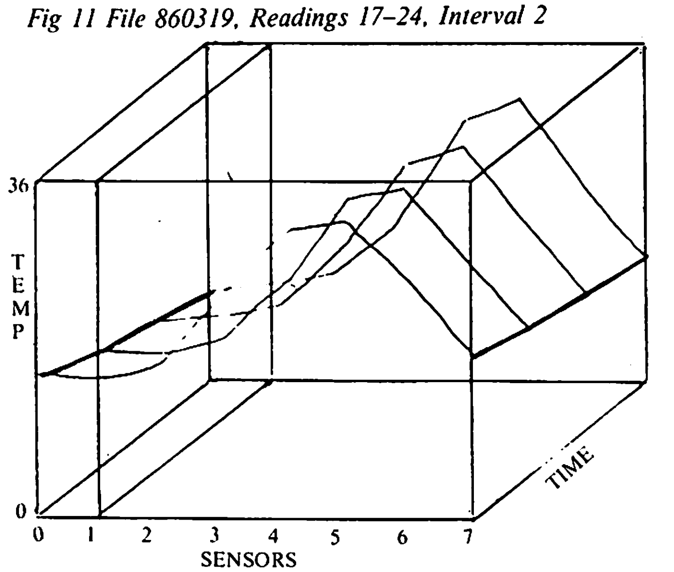


Fig 9 File 860319, Readings 9-16, Interval 2

installation (1325 to 1425 h); whilst figure 10 shows that the peripheral temperature decreased slightly and that the temperature towards the outer combs began to fall; due to bees beginning to form a cluster.

Throughout the period the bees maintained recognised brood rearing temperature at the centre of the cluster (figures 9, 13-14).

Fig 11 File 860319, Readings 17-24, Interval 2



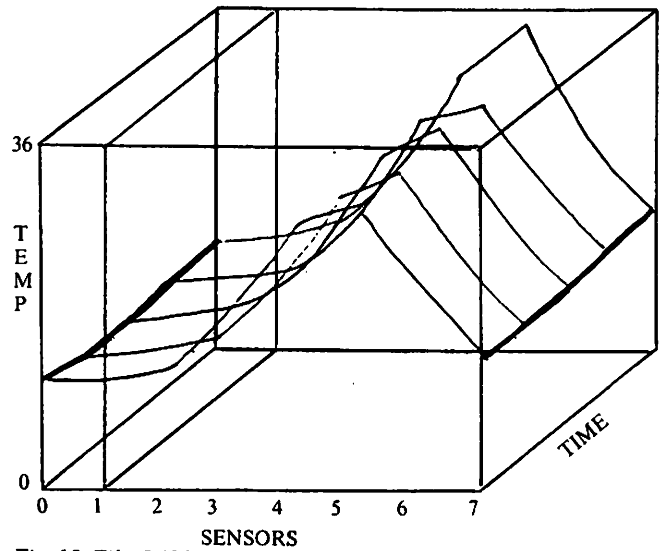
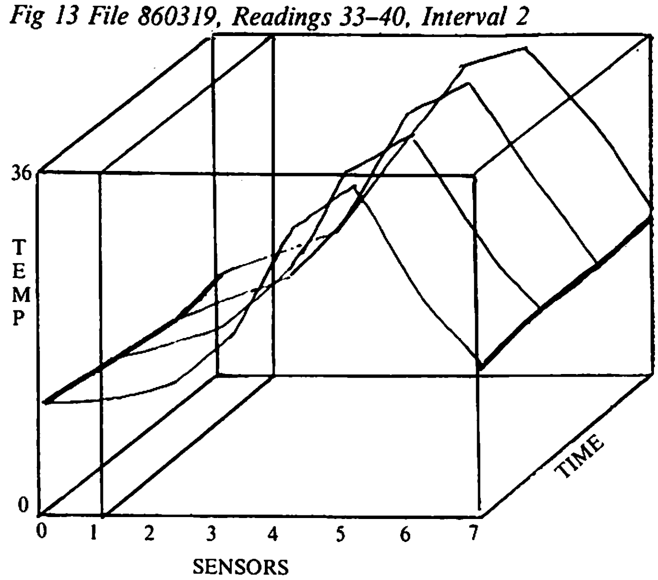


Fig 12 File 860319, Readings 24–32, Interval 2

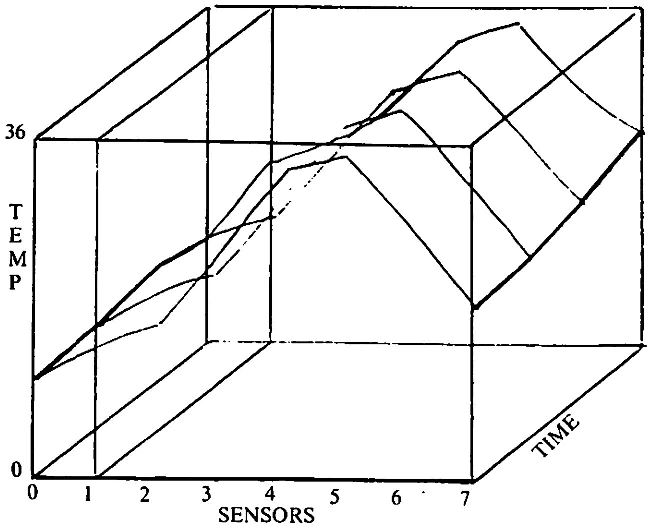
Fig 13 File 860319, Readings 33–40, Interval 2



4 Discussion and conclusion

The RS 590 PTAT transducers accurate to + or -0.2°C as installed have enabled a cheap, effective, computerised hive monitoring system to be produced. It is capable of use in cross referencing with meteorological data in real time and has potential for determining hive activity. Extension of the project to capture other data has been shown to be achievable with the same basic system.

Fig 14 File 860319, Readings 41–48, Interval 2



Alternative temperature, load cell and RH% transducers and a Langstroth hive are to be used for comparison purposes. The system was automatic and eliminates manual data processing or hive manipulation after installation.

Fifty-four (Szobo, 1985) to 768 (Mapp, 1986) sensors have been installed in a hive. This experiment used eight sensors (figure 4). A multiplexer allows several sensors to be read in turn and the signals sent down a common line to the same 8 channel ADC to be read by the computer. The same transmission system may thus be used with, for example, 64 sensors without any major change, but greater numbers of transducers and greater volume of data needs associating with usefulness of results. Simple reprograming may be used to alter the number and frequency of sample periods for storage on the microdrive tape. Automatic recovery and processing of data is intended to be used to map and cross correlate to ambient conditions and hive designs to improve management practice in given conditions. It has been shown (Szabo, 1985) that 3D maps of cluster size may be made by judiciously associating temperature profiles to cluster boundary.

Using inexpensive components good graphical and tabular display of accurate, dependable sensor outputs can be achieved. Transfer of data to the PDP enabled use of such tools as 'Mini-tab' statistical package for further processing. The basic system is very versatile and is already in use to aid monitoring pig activity in farrowing accommodation.

References

Agricultural Research Service USDA (1971). The thermology of wintering honey bee colonies. *Technical Bulletin No 1429.*

Fearns S (1985). "Sender" — a program for data transfer from ZX Spectrum. Seale-Hayne College Computer Unit Internal Report.

Minnick D R, Murphy M (1974). The effect of population density on the maintenance of cluster temperatures by the honey bee *Apis mellifera L. American Bee Journal,* 114 (6), 210–211.

Mapp D F A (1986). Private communication.

Möbus B (1986). Private communication.

Nunez J A (1979). Comparative study of the thermoregulation between European and Africanised *Apis mellifera* in Brazil. *Journal of Apicultural Research,* 18, (2), 116–121.

R S Components Ltd (1983). Semiconductor temperature sensor. *R S Date 3992.*

Szabo T I (1985). The thermology of wintering honey bee colonies in 4-colony packs as affected by various hive entrances. *Journal of Apicultural Research* 24 (1), 27–37.

Bibliography

Allwell D (1983). Beehive temperature meter. *Everyday Electronics.* February 1983.

Butter C G (1974). *The World of the honey bee.* Collins.

Cluley J C (1985). *Transducers for microprocessor systems.* Macmillan.

Corkins C L (1932). The temperature relationship of honeybee cluster under controlled external conditions. *Journal of Economic Entomology,* 25 820–825.

Doull K M (1983). *A practical introduction to electronic circuits,* Cambridge University Press.

Agricultural Engineering in Third World Countries — Part II

B A May

5 Some agricultural engineering technical achievements and challenges

FARMERS in the Third World have been using hand tools for thousands of years, draught animals for centuries and mechanically powered machinery for decades. During the past 50 years, agricultural engineers, with the help of ergonomists, have made some improvements to hand tools, few of which have been accepted by the farmer. They have developed equipment and techniques for use with draught animals and introduced mechanically powered machinery in support of Third World agriculture. Early books (Hoffen, 1960) on mainly hand and animal drawn agricultural implements have now been supplemented by comprehensive guides (*Tools for Agriculture, 1987)* to appropriate equipment which may be purchased or perhaps manufactured locally. An outline of the functions for mechanisation and levels of mechanisation technologies, with degrees of sophistication are given in figure 5. (Rijk, 1986). Timescales for the introduction of each level of mechanised technology will, of course, vary from region to region.

Mechanisation has contributed to increased labour and land productivity, while decreasing costs of production. In some Third World countries agricultural mechanisation has been introduced with positive effects on social change, often involving additional rural employment opportunities. Sometimes the reverse has applied. For example, R D Bell, former Head of Overseas Department at AFRC IER, writes in a personal communication that '... work to develop a pyrethrum harvester in Kenya (1958) was discouraged because picking pyrethum was a labour intensive operation providing work for women and children. The consequent high cost of pyrethrum led to manufacture of synthetic substitutes. Development of a semi-manual picker may have been more beneficial to the farm labour than trying to stop progress.' Mechanisation has probably been most successful in countries where there has been an appropriate application by farmers of hand tool, animal draught and mechanical power technologies for specific farming systems. Technical suitability and economic and social objectives will also have been

Part I of this paper appeared in the previous issue of The Agricultural Engineer. (Volume 43, No 3), which included a summary of the paper and details of the author.

Fig 5 Functions for mechanisation and levels of mechanisation technology with degrees of sophistication

Function or operation	Level of mechanization technology		
	Hand tool	Draft animal	Mechanical power
Land clearing	Brush hook Hand saw Motor chain saw	Buffalo and elephant for skidding and loading	Track-type tractor for clearing Skidders for log transport
Land development	Spade, hoe Basket Wheelbarrow	Earth scoop Leveling scraper Bund former	Wheel tractor Track-type dozer Motor scraper Excavator
Land preparation	Hoe Spade	Wooden plow Steel plow Spike harrow Disk harrow	Single-axle tractor Power tiller Two-axle tractor with various implements
Planting or seeding	Seed distribution by hand Planting stick Jabber Row marker Hand-pushed seeder	Furrow opener Marker wheel for dibbling Seed drill Seed-cum-fertilizer drill	Tractor seed drill Seeding with aircraft
Transplanting	Hand-operated paddy transplanter		Motorized paddy transplanter
Harvesting	Finger-held knife Sickle Scythe Threshing table Pedal thresher	Peanut lifter Cutter bar mower Reaper Reaper binder Treading (threshing)	Power reaper Power reaper-binder Power thresher Combine harvester
Crop husbandry	Hoe Weeding hoe Hand sprayer Water can Irrigation scoop	Wooden interrow weeder Walking-type tool carrier Riding-type tool carrier Spraying machine Persian waterwheel	Interrow weeder Motor knapsack sprayer Tractor boom sprayer Spraying with aircraft Diesel or electric irrigation pumps
On-farm processing	Pestle and mortar Flour grinding stone Hand-operated paddy husker	Animal-powered sugarcane crusher Power gear for driving processing machinery	Single-pass rice mill Rubber roll rice milling unit Hammer mill
Crop storage	Sun-drying Bag storage		Artificial dryer Bulk storage
Handling	Carrying Wheelbarrow Sack truck		Elevator Fork-truck
Rural transport	Porter Push cart Rickshaw	Sled Pack harness Bullock cart	Power tiller with trailer Two-axle tractor with trailer Truck

matched in some way to local circumstances.

Frank Inns (1988) argues that the difficulties of transferring technologies from the industrialised to the developing countries became clear by the early 1960s. Many of the technologies which have been developed in recent decades and labelled as appropriate, were initiated outside the Third World and kept going in the short term by enthusiastic initiators and sponsors. He believes that 'the characteristics of technology which have been successfully applied in the Third World are: socially and culturally acceptable, affordable by the owner, user friendly, user controlled, reliable and spontaneously adopted.'

Robert Bell in his personal communication draws attention to some of the problems arising from tractor use: 'In the 1950s and 60s it was generally believed that introduction of tractors would lead to major increases of production. That the bigger, more prosperous farmers would adopt new methods and that the benefits would 'trickle down' to the poorer sections of the community. The *trickle down* idea lost favour and efforts were made to provide tractor hire direct to small farms, so that all might share in the prosperity.

Tractor hire was generally mismanaged and either failed to pay its way or to satisfy any section of the farming community. *Small is beautiful* gained favour in the late 60s and early 70s but was, in many cases, coupled with attempts to cut out middlemen so leading to a weakness of service. It also led to provision of implements to farmers who lacked the scale of enterprise or management to make farming *a business.*

Non-renewable energy implications of mechanisation have given some cause for concern in the Third World, especially in the 70s. Location of the world's oil reserves, shown in figure 6 (Lacey, 1981) is an important factor in determining where agricultural mechanisation is most likely to advance in terms of mechanical power. Agriculture world-wide is, however, only a modest energy consumer, accounting for about 3.5% of commercial energy use in industrialised countries and 4.5% in developing countries as a whole. A strategy to double food production in the Third World through increases in fertilisers, irrigation and mechanisation would add only five per cent to present world energy consumption. This increase is considered to be only a small part of the energy that could be saved in other sectors in the developing world through appropriate efficiency measures (Our Common Future, 1987). Agricultural engineers in the Third World can therefore be justifiably proud of the many technical achievements which have contributed to increased food production. A few of these achievements will be considered in the following sub-sections.

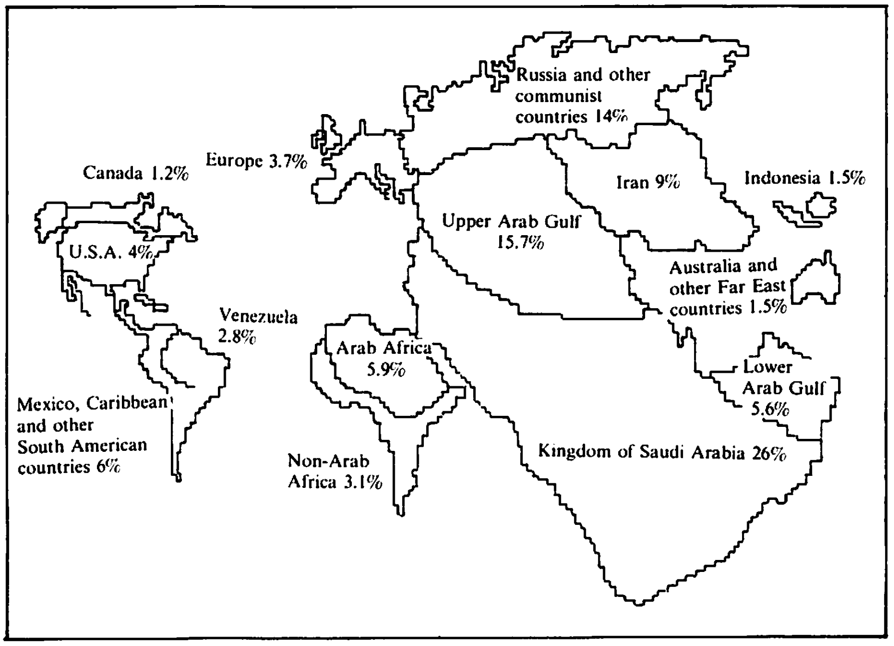


Fig 6 The world's oil. Countries have been sized according to their percentage share of the world's oil reserves at the beginning of 1980

5.1 Water

Water is a fundamental requirement both for plants and animals. Its availability in Saudi Arabia, for example, with the help of oil revenues and centre pivot/deep-well irrigation technology, has enabled agricultural areas to increase from 150,000 hectares in 1975 to 2.6 million hectares in 1987. This is despite conditions of extreme aridity, salinity, soil infertility, land use and labour difficulties. The Kingdom now claims virtual sufficiency in wheat, milk and dairy products, poultry and eggs, fish and dates. Attention is now being given to vegetable, fruit and flower production for target markets in the Middle East and Europe. In the same period almost as many trees have been planted there as were blown down in South East England during the 1987 hurricane disaster. The problem of long-term availability of water in Saudi Arabia and elsewhere in the arid regions of the world is recognised. Solutions are being considered, most of which involve agricultural engineers. For example, trickle, drip and bubble irrigation systems are now being introduced in many areas. Some of these systems are computer controlled for maximum efficiency.

In contrast, the axial flow pump is now the most widely used small farm machine in Thailand (Chinsuwan & Cochran, 1986). It was designed to suit local requirements of low lift and high capacity. The original design first became available commercially in 1957. Since then the pump has almost completely replaced the traditional wooden trough waterlift system. Using the original basic concept that met the requirements of small farmers, the pump was designed by agricultural engineers. The private sector agricultural engineers then provided most of the modifications and adaptations necessary to enable the two-wheel tractor to be used as a power source. Over 600,000 units of the axial flow pump were used in 1983. Most of these were locally produced and represent about 70% of all pumps used in Thailand. The use of the pump supports single cropping and double cropping rice production systems and continuous cropping in the central plain.

Jon Beeny writes from the Baluchistan Minor Irrigation and Agricultural Development Project in

Quetta, Pakistan, 'The most dramatic change over the last 15 years here in Baluchistan has been the spectacular expansion in the area of irrigated fruit production. Trickle irrigation is held by many to be the universal panacea, and so it could be in the correct context, power cuts and sociological water sharing rights permitting. But somehow it is not. Many of the demonstrations of trickle irrigation have been far from spectacular. This is believed to be due to the inherently risky nature of the method, relying as it does on precise applications of small quantities of water with little water held in reserve. Were it possible to develop more visible methods of ensuring continuity of trickle water delivery, reliable failure alarms and to find ways of reducing the needed pressure upstream of the filters; the uptake of trickle irrigation might proceed along safer and faster lines.'

Massive scale development is sometimes necessary to achieve the desired progress. For example, Syria's Euphrates Irrigation Project is an enormous undertaking even by international standards (Euphrates Irrigation Project, 1981). Agricultural engineers are working with civil engineers on the project. In addition to the production of electrical energy and the creation of an expanded fishery industry, the Euphrates Dam will enable the country to irrigate a further 640,000 ha of agricultural land during the next 30 years. Improved soil and water management techniques are, however, essential to contain the salinity and gypsum deposition problems.

5.2 Soil conservation

In the 60s and 70s the practice of shifting cultivation increased to unacceptable levels since it represented a major cause of soil erosion in developing countries. At a conference (Shifting cultivation, 1974) it was estimated that about 30% of the world's exploitable soils were under shifting cultivation. Shifting cultivation is practised in Africa, South America, Oceania and South East Asia.

The need for soil conservation and management in the Third World was discussed at an expert consultation (Soil conservation, 1977). It recognised that the seriousness of soil degradation and loss of soil fertility due to indiscriminate misuse of agricultural lands, forests and grazing lands now represented one of the most serious problems arising in areas already under cultivation. It was concluded that several practices in Third World agriculture have resulted in misuse and degradation of previously fertile land. Bad cropping patterns, unsuitable cultivation techniques, misuse of tractor power, improper choice of implements and machines, the abuse of natural pastures and forests, the extension of cultivation to marginal and submarginal lands and faulty irrigation and drainage systems were considered to be the major reasons for the soil degradation problem.

The importance of a multi-disciplinary approach to the solution of the problem was emphasised. Agricultural engineers feature prominently in this. Norman Hudson (Soil Conservation, 1977) gave the consultation clear guidelines on the research needs for the advancement of soil conservation in the Third World. The effects of soil degradation on the development and decline of civilisations from pre-history through to the present day have also been considered by Hudson.

The true test of technical achievement for the agricultural engineer is not at the research or prototype stage, but after several years of successful use in the hands of the farmer. For example, serious corrosion problems are now beginning to be identified in centre pivot irrigation systems in the Middle East. More importantly, a recent conference of the International Commission on Irrigation and Drainage (ICID) has examined ways of tackling what has now become a major obstacle to the increase of food and fibre production: the deteriorating state of many irrigation schemes, together covering more than 115 million hectares. Reports from many countries of the Third World indicate a serious waste of water through seepage, neglected maintenance of channels, pipelines and key installations, inept administration and management, inadequate concern for the needs of the water user, inequitable distribution of supplies and a serious and continuing growth in salinity. On average only one-third of available water is used by crops; more than half is wasted. To remove these losses would produce dramatic effects on food production.

Despite these problems, Haj Altar from the Ministry of Agriculture and Land Reform in Morocco asserted that: 'For a large number of African and Asian countries, irrigated agriculture is unquestionably more advantageous than the rainfed sector.'

Wind erosion is still a serious problem in parts of the Third World despite the devastating years of the 1930s when the winds blew across the Great Plains of the United States picking up the dry topsoil and scattering it like black snow over Chicago, New York and Boston, resulting in one of the worst man-made ecological disasters in world history (Worster, 1982).

In 1968 a drought set in across the Sahel in Africa. For six years the people and the land struggled to survive — and often failed — as a Sahelian dust bowl became established. The problem is still with us today and, despite continued effort by teams of dedicated specialists, including agricultural engineers, the solutions are slow to emerge and difficult to apply.

Erosion makes soil less able to retain water (when it is available), depletes it of nutrients and reduces the depth available for the roots to take hold. As a result, land productivity declines. Top soil eroded by surface water is carried to rivers, lakes and reservoirs; silts up ports and waterways; reduces reservoir storage capacity and increases the incidence and severity of floods.

The problem of soil erosion has become widespread in the Third World. In India soil erosion affects 25–30 per cent of the land under cultivation (Centre for Science and Environment, 1985). According to an FAO study (Land Food and People, 1984) the total area of rainfed croplands in Asia, Africa and Latin America will shrink by 544 million hectares over the long-term because of soil erosion and degradation unless conservation methods are applied. This situation represents an important and vital challenge for the agricultural engineer.

5.3 From animal draught to tractors

In field mechanisation, many of the technical achievements have been centred around draught animals. An indication of the importance of draught animals is given in figure 7 (Muzinger, 1982). Constantinesco (1962) wrote that, 'the ox-drawn

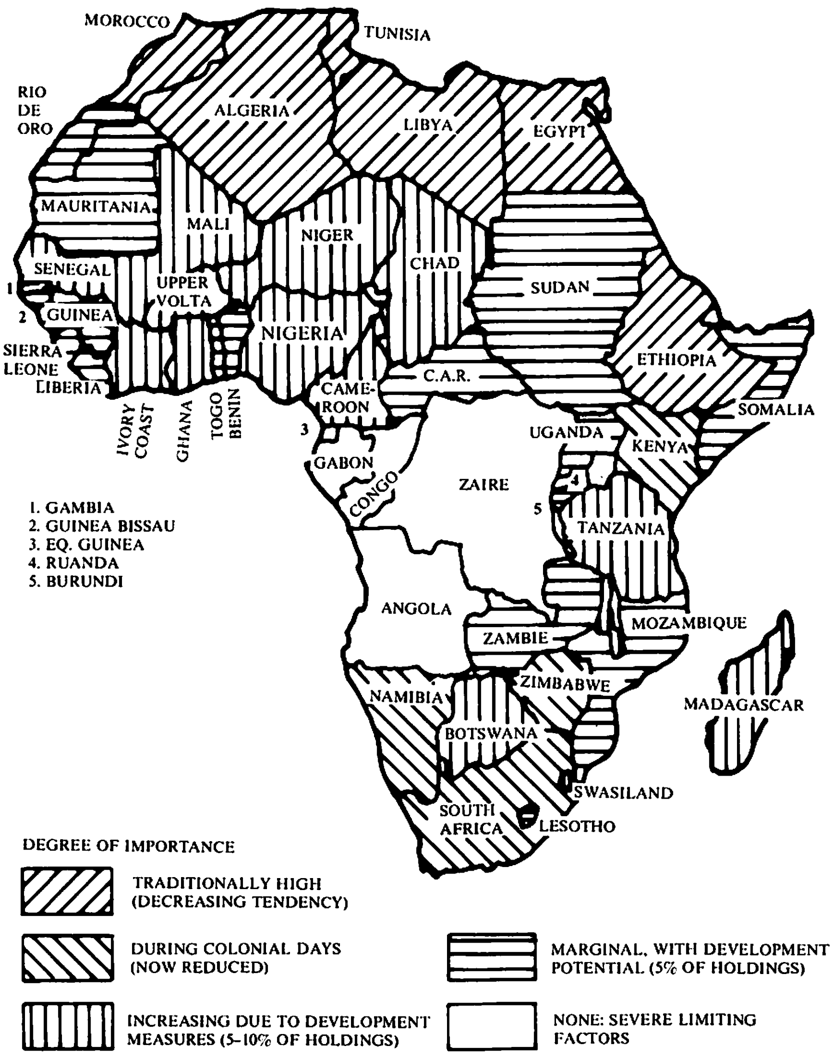


Fig 7 Importance of draught animals in Africa

toolbar has been receiving considerable attention in East Africa within recent years, particularly in Tanganyika and Uganda, and development work has been in progress in conjunction with the NIAE in the UK. The NIAE has now developed and constructed an experimental ox-drawn tool-bar to be capable of ploughing, ridging, cultivating and sowing seed, while provision is also made for fixing a cart body for transport. Samples of these have recently been sent to Tanganyika and Uganda for test.'

Taking note of the UK initiative together with French and Australian developments, Constantinesco suggested that, 'with the information now available it should be possible to design an ox-drawn toolbar to meet the needs of as many Afro-Asian countries as possible in one machine. This should enable manufacture of sufficiently large quantities of toolbars at the lowest possible cost and thus be saleable in a wide enough market.'

The idea was sound in theory, but according to Starkey (1988) the results have not been encouraging in practice. A review of the available information has revealed a large discrepancy betwen optimistic research reports concerning wheeled tool carriers and the reality of their repeated rejection by farmers.

In Senegal, for example, after early optimistic reports, numbers of wheeled tool carriers increased rapidly to a peak of around 1000 units in 1968, but have declined steadily ever since. Despite half a million draught animals in regular use in Senegal, sales of tool carriers had dropped to 3 by 1983.

In the Gambia about 900 wheeled carriers were imported between 1965 and 1973. By 1976 the only tool carriers still in use were being used simply as carts. In Botswana the manufacture of wheeled tool carriers began in 1975 after optimistic pilot studies by research and development workers. Problems arose in practice and the workshop making toolbars ceased production in 1978.

In India and Latin America, Paul Starkey claims, the stage now reached is similar to that of Senegal in the 1960s or Botswana in the 1970s. He suggests that a disappointing technology promotion that is well-reported can be a valuable lesson for all concerned and can prevent limited aid funds being wasted.

In a personal communication, John Ashburner, working for FAO in Niger, writes: 'Why is it that in the developed world we were so successful in applying animal power to our agriculture and yet this does not seem to be so easy to apply in the Third World. My own impression is that we had the Industrial Revolution to back us up — the Third World is still struggling to establish at least the basic infrastructure of village blacksmiths. There is an important social element too — technicians such as blacksmiths, mechanics, plumbers, carpenters, etc, are at the lowest end of the social scale in countries such as Niger. How much does it cost to hire a plumber in UK these days?'

Suri (1978) has drawn attention to the competition animals create for available land. He estimates that there were approximately 50 million bullocks in India in the late 70s. To double food production using animal power would require another 50 million bullocks. Meeting their fodder requirements would take the equivalent of land required for feeding 200 million humans. The development of farm power supply in India from 1951 to 1976 is presented in figure 8.

Robert Bell writes in a personal communication: 'Animal draught has been proposed and is currently very much in fashion. I do not understand why it is often considered proper to provide free or subsidised veterinary services and drugs but not to support tractor service organisation. Success with animal power has been very variable and in the past it has been too empirical. It is hoped that animal power will soon be better understood, but it is clear that droughts etc., can have a devastating effect on ability to cultivate in the succeeding years (much as failure to provide parts to maintain tractors has an effect in successive years). In

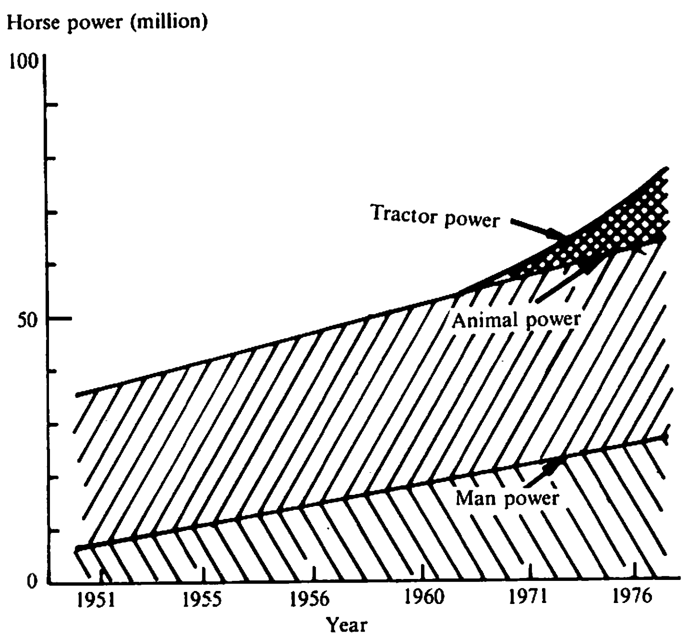


Fig 8 Farm power supply in India (Source: Agricultural inputs Division, USAID, New Delhi)

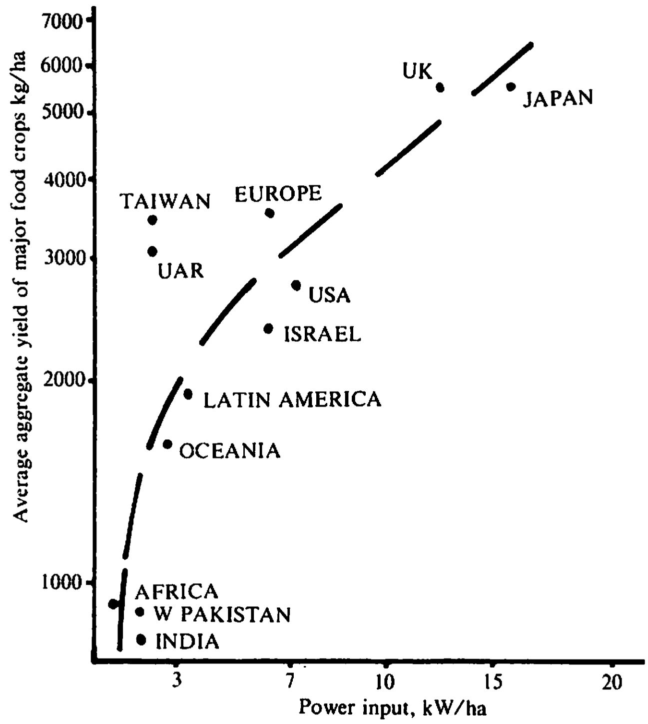


Fig 9 Relationship between yield and power input (Source: Verma, 1972)

some case the main benefit of animal draught has derived from the sale of the mature stock.'

There were many reasons for the change from animal to mechanical power in the Third World. Crossley (1978) for example, draws attention to the importance of timeliness in cultivations and planting which may be achieved under several conditions by working in the dry season. To achieve this necessitates the use of mechanical power. In countries such as Africa and India it is suggested that a tenfold increase in power is necessary to achieve reasonable productivity; this is illustrated in figure 9. Willcocks (1984) suggests that the chosen tillage system under semi-arid conditions has a high work rate which can only be provided by mechanically powered methods.

5.4 Production of tractors and agricultural machinery in the UK for the Third World

Gego (1986) has suggested that despite potential benefits, change from animal to mechanically powered farming systems will always be a slow process in the Third World. One method of accelerating this has been to transfer technology from the North to the South in the form of manufactured goods.

Many would argue that the single greatest contribution made to Third World agricultural development by any agricultural engineer during the past 50 years was the small tractor invented by Harry Ferguson. In the 1930s Ferguson was the first engineer to visualise the tractor and implement working together as a single integrated machine rather than operating as two units. 'Agriculture' he said, 'is more important to mankind than all other industries put together. Yet it is the only industry conducted by antiquated methods.' The British equivalent of the Ferguson tractor was called the TE 20 and was produced from 1946 by the Standard Motor Company at Coventry. 'Only one idea in ten thousand succeeds' claimed Ferguson. His idea clearly was one of the successes. Thirty-four implements were being offered with the tractor by 1952, including several of direct relevance to the Third World to where many tractors were exported. The two millionth Ferguson system tractor was produced at Coventry in 1974. Over the years export sales are estimated to have earned the UK at least £1000 million (or US billion). Its simplicity, reliability and ability to transfer implement weight to the tractor, producing wheel grip and traction, has benefited developed and developing countries alike in their agricultural production systems.

Many modern tractors are derivations of this ingenious concept. What mattered to Ferguson was the satisfaction of engineering excellence. A saying of his was hung on the walls of every design department he headed. It said: 'Beauty in engineering is that which performs perfectly the function for which it was designed and has no superfluous parts.'

Today, the United Kingdom is the world's largest exporter of agricultural tractors. The main destinations of UK exports of tractors to Third World countries (1974–84) are given in table 4.

Information about UK exports of farm machinery is given in table 5.

Both of these tables have been developed from information in the Agricultural Engineers Association Data Book 1974–1984.

Over the period, Third World sales of tractors have risen from 26% to 32% of worldwide UK exports. Corresponding figures for farm machinery are nine per cent and eighteen per cent respectively.

5.5 Production of tractors and agricultural machinery in the Third World with particular reference to India

In recent decades, India is perhaps the leading country in the Third World in the field of local production. Mohan (1986) has described pre-independence Indian agriculture as a largely rainfed traditional practice with a few isolated irrigation schemes using

Table 4 Main destinations of UK exports (units) of agricultural & tracklaying tractors to Third World countries 1974-1984

	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Columbia	727	527	698	884	766	102	35	38	14	23	47
Ecuador	174	408	169	377	145	137	209	118	59	24	36
Egypt	11	335	309	635	452	48	50	35	4	5	206
Ghana	395	275	420	420	320	54	104	266	145	64	63
India	3625	4723	6304	4910	5855	8662	5355	6663	372	129	58
Iran	547	594	126	165	1137	3	2834	1588	3	4	1254
Iraq	0	380	73	65	168	52	2634	8257	908	89	0
Kenya	366	476	433	1316	1155	589	705	452	252	231	379
Libya	1433	1183	1010	1718	1653	1933	2195	3077	4299	4172	4574
Malaysia	906	1078	630	503	982	926	1119	777	427	196	337
Mexico	2893	402	396	92	683	435	2611	7000	3385	2360	2817
Morocco	1179	501	1415	1468	1947	1485	1088	262	494	353	294
Nigeria	461	1515	1141	2141	898	113	1027	994	980	190	198
Pakistan	2080	5761	10272	7686	4489	7679	7265	3915	14118	9340	20319
Philippines	1292	1829	630	310	296	438	251	289	74	82	5
Saudi Arabia	182	570	726	714	1664	1804	1792	2149	701	1266	709
Sri Lanka	49	155	7	834	2057	2234	1752	110	138	456	375
Sudan	895	1102	1559	584	454	330	633	578	446	363	617
Thailand	2457	3390	3237	4171	2115	1293	2663	1956	613	1361	1513
Tunisia	491	859	697	756	451	283	443	392	475	117	269
Turkey	7453	12116	19413	7572	528	126	226	1316	2778	3	996
Venezuela	696	2340	1990	1922	421	779	408	657	675	208	204
Total Third World countries	28312	40519	51655	39243	27148	29505	35399	40889	30932	21036	35260
Total EEC countries	16594	20792	28922	31168	27123	25905	14824	13708	20215	21447	23979
Total EFTA countries	16275	22057	20552	21670	13204	13072	15246	11100	10859	10123	7757
Total other countries	46710	52921	39729	33996	31913	41326	42666	29020	18826	25616	27458

Table 5 Main destinations of UK exports (£ x 10^3) of agricultural machinery to Third World countries 1974-1984

	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984
Algeria	142	396	201	610	766	235	432	95	23	89	214
China	22	34	10	12	33	25	5	2	22	106	1587
Cyprus	105	159	222	211	223	303	386	225	261	527	567
Egypt	41	326	260	630	748	1024	948	1679	4580	4136	3318
Ghana	330	243	345	470	613	292	498	1055	699	210	1176
Iran	668	1319	1785	4261	5522	819	3743	2152	1280	2087	2229
Iraq	939	2310	2242	1016	2116	943	4811	3990	2007	1168	2690
Kenya	505	673	313	1190	1260	596	1185	1101	531	595	740
Libya	1114	1925	1234	2113	653	1135	318	1132	83	674	1050
Malaysia	374	265	230	796	395	646	596	221	527	893	612
Mexico	373	139	128	74	634	490	517	1053	654	697	1860
Nigeria	976	1895	3648	4926	4487	1465	2054	10706	14071	3266	2772
North Yemen	7	38	58	73	59	105	568	72	484	979	672
Oman	63	228	199	185	724	315	326	373	684	968	739
Saudi Arabia	392	2104	1290	5742	2019	3238	2806	3316	5110	4451	5947
Singapore	279	284	245	361	531	793	773	1231	1053	689	756
South Korea	88	360	344	161	81	410	54	106	238	73	825
Sudan	91	526	242	441	1267	774	1267	639	520	688	489
Tanzania	528	376	355	588	970	888	1124	568	566	276	1015
Thailand	251	390	815	369	333	141	365	192	326	307	1265
Total Third World countries	7288	13990	14166	24229	22174	14637	22776	29398	33719	22879	30523
Total EEC countries	36165	41935	55572	76602	89541	94086	76966	63265	67646	59076	69659
Total EFTA countries	8394	8542	9417	12987	9506	10992	10982	10827	11059	8428	10548
Total other countries	25659	45501	40693	49837	47583	51675	57991	46215	44507	48958	63676

canals, tubewells and Persian wheels; wooden ploughs drawn by 45 million sickly bullocks; seed strains handed down through generations and no chemical fertiliser or pesticides. The country with 132 million hectare under cultivation did not produce enough to feed its 369 million people and famines were common.

After Independence, agriculture received the highest priority of national government. In the 1950s, major initiatives were taken in agricultural education and research, and agricultural mechanisation began in the late 1940s with the introduction of imported tractors. Acceptance of mechanisation was slow, however, and by 1960 tractor numbers barely exceeded 10000.

A tractor industry was born in India during the period 1959–65 when imports were restricted and five tractor manufacturing units were set up by the private sector, all with foreign collaboration. During the early years the units were mainly concerned with the assembly of completely knocked down (CKD) kits. Local manufacture was confined to simple components and sheet metal covers. By 1965 indigenous tractor production had risen to 6000.

The successful introduction and acceptance of high-yielding seeds in the late 60s produced a rapid increase in the demand for tractors. In 1970, 33000 tractors were supplied compared with 13000 in 1967. The high demand and supply boosted tractor prices. To help to meet demand, import of tractors was liberalised. Imports accounted for 40% of the 1970 supply.

The performance of the local manufacturing units did not meet government expectations in the late 60s, local content of tractors remaining within the 50–70% range. Government therefore de-licensed the tractor industry in 1968 and invited new proposals. As a consequence of this, six new manufacturers entered the industry and the combined output of the eleven units rose to 32000 by 1975. By 1984 manufacturing units had increased to 13 which together produced 81000 tractors, although national production capabilities are substantially higher.

Singh (1978) has presented information on indigenous production and imports of tractors in India 1961–76. This is presented in figure 10. Singh also reports that the production of power tillers began in India in 1963. Total production of power tillers in 1975–76 was 2540 against a licensed capacity of 40000 per year. Progress in the manufacture of pumps for irrigation has been rapid. The large seal pump manufacturers have a total installed capacity of 508000 units per year, 95% of which are agricultural pumps. There were 1500 registered units in various states manufacturing mainly animal-drawn agricultural implements. Large quantities of rice mills are made in India. The number of fruit and vegetable processing industries also increased from 90 in 1961 to around 1200 in 1975. In the late 1970s, India became a strong exporting nation for agricultural machinery, including tractors, threshers, implements, engines and pumping sets. Exports were sold to South East Asia, Africa and the Middle East.

As Indian celebrations proceed to mark 40 years of Independence, agriculture accounts for 36% of the Gross Domestic Product, grain production has almost tripled and thanks to the maintenance of large buffer stocks of food, famine is no longer feared and the 1987 drought, the worst since Independence, at the national level produced no more than a serious economic setback. At the household level there was suffering, especially in the poorer areas. A bigger shift in resources from the richer to poorer states will be needed to resolve this, including tractors, associated mechanisation and a massive extension of appropriate irrigation technology.

In Latin America, tractor production has been proceeding steadily since 1962 (The Agricultural Machinery Industry, 1983). Table 6 gives brief details. Very little machinery is produced in Africa (The Agricultural Machinery Industry, 1983). Table 7 shows Africa's sources of imported agricultural machinery in 1979.

Introducing the Proceedings of a conference held at Silsoe John Kilgour (1978) writes, 'It has long been assumed by some enthusiasts that the small farmer in a developing country can escape from the vicious circle of low production and low income, simply by purchasing a small tractor. In the past many people spent a lot of time and effort in

Table 6 Production of agricultural tractors (units) in Latin America 1962-1982

	1962	1967	1970	1976	1980	1982
Argentina	10981	9664	10642	24098	3658	3889
Brazil	7586	6219	14029	65279	57975	32246
Mexico	—	3952	4116	11574	16496	14528
Totals	18567	19475	28787	100951	78128	50663

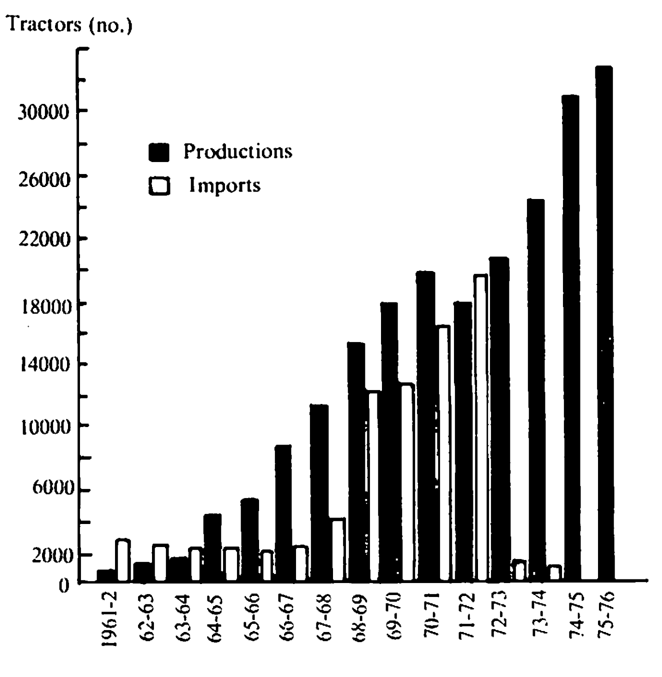


Fig 10 The indigenous production and imports of tractors in India (Source: Energy in Indian Agriculture, 1976)

Table 7 Africa's sources of imported agricultural machinery — 1979

Importers	Exporters							
	Western Europe	USA and Canada	Other developed countries	Developing countries	African developing countries	South Africa	Other	World
All developing Africa	349737	75151	45046	9855	2882	1780	2647	487104
Africa late developing countries	66174	18623	12719	3974	1182	1720	—	104397
Total Africa	442634	122484	56060	22004	2882	1780	2647	650496
Total World	6343628	3567153	1696974	228679	4522	10708	28200	11879868

designing a *suitable* tractor, but after many years and many designs the small tractor has not been widely adopted in developing countries.' With the exception of single axle units in South East Asia the choice would seem to rest between animals and the larger mass-produced derivatives of the TE 20.

5.6 The IRRI thresher

One further example of technical achievement for an individual machine will be considered in order to illustrate the excellent work undertaken by CGIAR Institutes generally and by IRRI in particular. This example concerns Asian axial-flow threshers and is based on a paper written by an IRRI worker (Khan, 1986). The threshers were developed within the IRRI Small Farm Machinery Development Programme which was established in 1967. This programme focuses on working closely with small rice farmers to provide farm machinery through indigenous manufacturing channels in developing countries. The programme is active in many parts of Asia and Africa. As a result of this programme, several new machines have been introduced to farmers on a significant scale. The axial-flow threshers developed at IRRI in the early 70s are now widely used in ASEAN countries, notably The Philippines, Thailand and Indonesia.

The first thresher was a large pto-powered machine with a rotary grain separating and cleaning mechanism. This machine was developed originally for use in The Philippines to compete with tractor powered McCormick-type threshers. The machine was not commercially produced because of concern about labour displacement. In Pakistan, however, which has a shortage of labour at harvest time and a large tractor population, a pto-powered thresher was developed during the period 1976–81. This work was undertaken within the IRRI-PAK Agricultural Machinery Programme and is now commercially produced in Pakistan.

During 1971–72 a smaller axial-flow thresher (Model TH3) was developed at IRRI for the South East Asian market, powered by a 7 hp air-cooled gasolene engine. A thorough field test programme was undertaken in The Philippines in 1972–73. As a result of subsequent improvements the machine became capable of threshing wet paddy at a rate of 1t paddy/h at a threshing loss of less than one per cent.

In 1973 four manufacturers in The Philippines began commercial production. In 1974 prototype machines were fabricated by manufacturers in Thailand, Sri Lanka, Indonensia, Pakistan and Vietnam.

By mid-1975 the axial-flow thresher was in commercial production by 15 companies in five countries. Khan reports that 'As the number of manufacturers increased rapidly, some poor quality machines were produced by manufacturers who were not quality conscious.'

Currently IRRI threshers and adapted versions are produced commercially in seven Asian countries involving several hundred manufacturers and well over 100,000 machines. In his conclusions, Khan makes two key points:

'1. The large variety of commercial designs that evolved from the original IRRI axial-flow thresher amply demonstrate the abundance of innovative talents among local manufacturers in developing countries. It also highlights the need for key innovations which can catalyse this vast pool of talent.
2. Most national agricultural engineering research institutions suffer from insufficient contact with local manufacturers. If their efforts are to have any meaningful contact at the farm level, it is essential that close working relationships are established with local industry.'

This latter conclusion is emphasised by Ahmed and Kinsey (1984) in connection with their African experiences. After reviewing case studies of farm equipment innovations in Kenya, Tanzania, Malawi, Uganda, Southern Sudan and Zambia they concluded that: 'since the case studies provide no evidence for widespread adoption of any single item of farm equipment originating from any R&D institution, despite decades of research, we are led to the inescapable conclusion that something is fundamentally wrong with most past and current R&D efforts (in Eastern Africa). The R&D efforts referred to involved solutions to farm equipment needs as seen by researchers rather than farmers. Manufacturers and innovators did not seem to have been involved at all.'

5.7 Technical achievements in the future

There are many more examples of agricultural engineering achievements and challenges in the Third World than those mentioned in the previous sections: The impact of the single-axle tractor, especially in South East Asia; cultivation techniques; developments in seeding and transplanting, particularly for rice; mechanisms for applying agrochemicals to improve soil fertility or for plant protection; harvesting, drying and processing equipment and methods for particular crops; the special mechanisation needs of livestock production, forestry, horticulture and aquaculture and for assisting the production of renewable energy.

Malcolm Cutler writing from Thailand suggests that an important area is: 'the development of appropriate low-cost processing facilities for farm and village whereby surplus crops can be processed for consumption throughout the year. Examples include fruit canning, juice extraction and drying. Also freezing and cold store facilities using solar or waste product energy.'

Despite Harry Ferguson's assertion that 'only one invention in ten thousand succeeds', it is certain that several of these areas will bring new achievements — and challenges for the agricultural engineer in the future which will be of lasting benefit to the farmer in the Third World. Many are already showing potential. Two will be discussed briefly; the Electrodyn sprayer and the Photovoltaic cell.

Rae (1985) suggests that the major disadvantage of the knapsack sprayer is the large volume of water needed. This applies particularly in the semi-arid areas of the Third World. This problem has been partially overcome with the ingenious invention of spinning disc applicators. Several examples of these applicators are available and widely sold throughout the Third World for the application of herbicides, particularly in the Far East, and for insecticides, especially on cotton in Africa and Latin America.

The volume sprayed on land in litres per hectare is reduced from 200 for the knapsack to between one and two for the battery-operated spinning disc. There are, however, disadvantages with spinning disc units which it is claimed are largely overcome by the Electrodyn sprayer invented by Ronald Coffee. In addition, spray volume is further reduced to between 0.5 and 1 litre per hectare. In his paper on Electrodynamic crop spraying (1981) Ronald Coffee refers to the development of highly-active but expensive pesticides during the 60s and 70s. He believes that most spraying operations are inefficient, wasteful and potentially hazardous to non-target organisms. He recognises that ULV techniques generally have already changed spray technology and believes that charged particle sprayers such as the Electrodyn may completely transform the technology.

Plate II Spraying cotton in Thailand with 'Electrodyn'

Patented in 1974, the Electrodyn received the Pollution Abatement Technology award in 1984. The system uses a unique electrodynamic atomisation process to produce uniformly-sized and electrically-charged droplets. This dramatically reduces spray drift and considerably improves operator safety. Ronald Coffee says that: 'the system has met with universal appeal in all of the countries in which it has been introduced.' He stresses that its main contribution will result from its being a highly appropriate technology with the potential to help to transform food production levels in many developing countries.

The range of application of the Electrodyn system is described by Pascoe (1985). Specific applications in Brazil are described by Smith (1988) in the form of three case histories. Matthews (1986) refers to studies in India which illustrate the considerable advantage in time and labour achieved.

Renewable energy in global terms is of considerable untapped potential. Renewable energy sources could, in theory, provide 10–13 TW annually, equal to current global energy consumption (Deudney & Flavin, 1983). Today they provide about 2 TW annually, about 21% of the energy consumed worldwide of which 15% is biomass and 6% is hydropower. Most of the biomass is in the form of fuelwood in the Third World and agricultural and animal wastes. It is suggested (Our Common Future, 1987) that fuel wood no longer be considered as a renewable resource in many areas because consumption rates have overtaken sustainable yields.

Amongst other renewable energy sources, windpower has been in use for centuries, mainly for pumping water. The fuel alcohol programme in Brazil produced about 10 billion litres of ethanol from sugar cane in 1984 and replaced about 60% of the gasolene that would have been required (Goldemberg *et al*, 1985). The use of gasthermal energy from natural underground heat sources has been increasing by more than 15% per year in both industrial and Third World countries (World Resources Institute, 1987).

At present the global use of solar energy is small, but it is beginning to assume importance in the energy consumption patterns of some countries. Solar water and household heating is widespread in many parts of Australia, Greece and the Middle East. The United States and Japan support solar sales of several

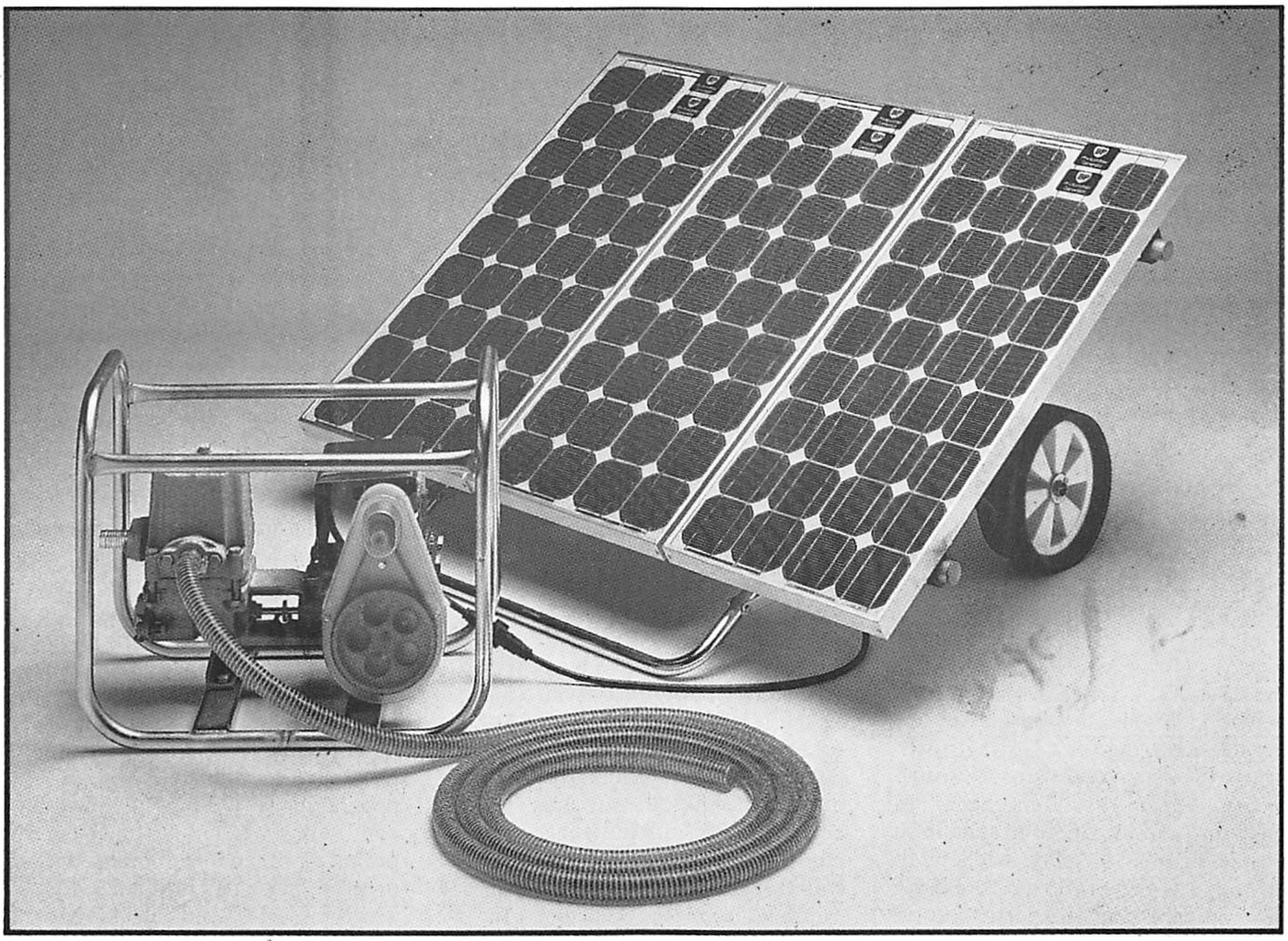


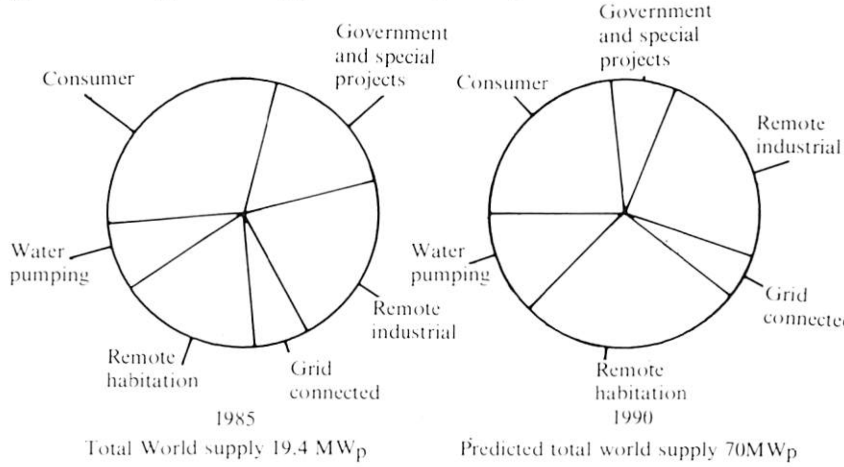
Plate III Solar powered positive displacement pump for small scale crop and animal water supply [*BP photograph*]

hundred million dollars a year. With constantly improving solar thermal and solar electric technologies it is likely that their contribution will increase substantially. The cost of photovoltaic equipment has fallen from around $500–600 per peak watt to $5 and is approaching the $1–2 level where it can compete with conventional electricity production (World Resources Institute 1987). But even at $5 per peak watt it still provides electricity to remote places more cheaply than providing power lines.

A number of developing countries now have active solar energy programmes. The Solar Energy Society of Zimbabwe, for example, has established a solar water pumping station in the University. At the practical level, Patrick Butcher, an agricultural engineer managing irrigation systems, writes from Indonesia: 'The great step forward in 24 hour monitoring is the micro-chip and solar panel along with rechargeable NiCad batteries at a price that, in general, can be afforded. We can now record water levels continuously and with the help of parshall flumes determine just where the water is going. Of course, at the end of the day we are relying on people, the farmer to operate his outlet in a prescribed manner and regular visits by the local instrument reader to interrogate the data loggers at the weather station and parshall flumes.

The United Nations Development Programme, collaborating with the private sector have held two Photovoltaic Information Symposiums, one in Kenya and one in Thailand. A booklet (*Photovoltaic Technology*, 1986) gives material discussed at these sessions. The potential for photovoltaics in Third World rural development strategies was seen to be considerable because the technology is simple, dependable and can be deployed on any scale. It was seen as one of the best technologies for meeting widely dispersed small power needs of rural communities.

Fig 11 World application of photovoltaic power [*Source: BP Solar International*]



Particular applications include pumping systems to provide clean drinking water for rural villages and for irrigating farmers' crops; systems to provide power for health clinics and vaccine refrigerators; systems to power vital communications networks that link distant parts of the country for various education and information purposes and systems which provide energy in village communities for houses, schools and community buildings. Present and predicted future world applications of photovoltaic power are given in figure 11.

6 Agricultural engineers in business

In April 1988 Honda became the first Japanese car maker to import its own cars from the United States; a turning point in the export strategy of Japanese firms which have 25% of the US market. Trading relationships between nations and businesses are rapidly changing on a North-North, South-South, and North-South basis. Agricultural engineers in business (and intending to remain in business) must take full account of these international trading developments and to participate in them actively and effectively.

Paraphrasing the words of Malaysian Prime Minister Mahathir, when he was addressng an EEC/ASEAN workshop on the development of business between the two regions in Kuala Lumpur in 1972: 'If businessmen have come to this conference believing that trade with ASEAN is a simple matter of appointing a local agent and then sitting back in London waiting for the order to arrive, then they could not be further from understanding our position. Gentlemen, we want commitment through regular and close contact, through detailed understanding of our needs and through partnership. There is no longer room for one-sided commercial exploitation in this or indeed in any other part of the developing world.'

Fortunately, I am regularly reminded during my own Third World travels that United Kingdom companies are amongst the most highly respected business operators in the world. The pre-independent qualities and attitudes of the British described by Sir Gerald Reece have in general been successfully transposed to business practices by British companies. It is important to ensure that these standards are retained as our international relations develop. If we have any serious fault in the eyes of the Third World it is that we are not sufficiently determined in our business relations, nor do we always give the impression of full commitment.

Travellers in the Third World, especially South East Asia, cannot fail to witness the evidence of a committed and determined Japanese export policy. Some of the deepest market penetration has been achieved in agriculture. More recently other South East Asian countries have followed the Japanese example.

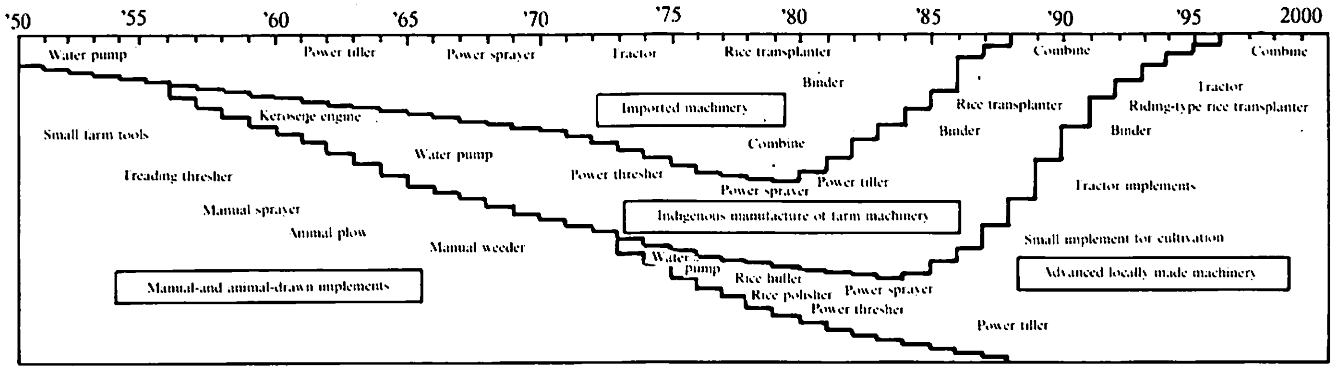
R M Lantin (1986) of the Regional Network for Agricultural Machinery based in The Philippines, has described the mechanisation for rice in Japan and Korea.

Like Japan, Korea used human and animal draught technology before the 60s. In 1965 there were still twice as many animal power users as mechanical power users. By 1979 power users had increased threefold. Draught animals continue to be used in hilly areas, but with present plans for mechanisation, at least 50% of the hilly areas will be using mechanical power by the end of the 1980s. An outline of farm mechanisation in Korea from 1950 to the year 2000 is given in figure 12. This mechanisation is being achieved with an average landholding of 1.35 ha. In 1983 about 50% of farm households owned three machines — power tiller, rice transplanter and reaper/binder and today almost all of these machines are produced locally.

Local research institutes are planning new, more advanced machines for the 90s and it is the intention to produce all of these locally. Will there by any surplus manufacturing capacity for selling machines back to the European farmer through joint Korean/European business ventures? The possibilities will require close evaluation in the 90s and beyond.

During the 60s and 70s, agricultural engineering companies in the North played a key role in supplying much of the necessary technology for agricultural development, food production and processing in the Third World. In most cases these technical inputs have been funded through aid programmes. Despite its past and continuing vital importance in the provision of technical inputs, the aid process presents problems to the Third World and its suppliers, particularly the businessmen concerned with individual products. A discussion with the British group of businessmen at an overseas agricultural exhibition raised a number of points. One machinery exporter recognised that the donor country, aid agency and receiving government must all be concerned about the ways in which the various sources of funds are applied. He believed, however, that often insufficient attention is given to the ultimate user of the product or to the supplier. Another exporter agreed with this and observed that all the decisions seem to be taken at high levels without enough involvement of those at the implementation level.

Fig 12 Farm mechanization in the Republic of Korea: past, present, and future



These arrangements do not seem to produce a sufficient sense of responsibility or accountability after delivery of the products. Funds are generally not provided for this and the idea of a supplier raising his offer price in order to provide operator training or a good level of after-sales service, runs the real risk of losing the contract. Interest at the higher levels in local government and the aid agencies seems to be concentrated on the setting up of projects, not on their successful operation. From our business experience in developed countries, it is after the tractors, pumps or sprayers have been supplied that the real need for technical support arises. It is the same in developing countries, but the support is generally not available.

Robert Bell in a personal communication writes: 'Through the 60s and 70s there was a regrettable tendency for orders for machines (especially tractors) to be purchased by state organisations without adequate attention being paid to building up commercial service organisations. Spares tended to be ordered at between ten per cent and twenty per cent of initial cost. This almost worked providing new and increasing orders for tractors were placed each year, but failed when cash was limited and no new orders for tractors were placed in some years. Only recently has there been reasonable attention given to provision of spare parts and to training of repair staff; there is still little emphasis on building up proper dealership networks to maintain tractors and implements. Few aid programmes (or domestic programmes of currency allocation) offer sufficient continuity to encourage suppliers to invest in service networks. One problem is that many components of tractors are similar to components of cars or trucks which may be restricted to conserve foreign exchange or the parts ordered to service tractors may be diverted to other uses.'

At a World Commission on Environment and Development public hearing in Jakarta 1985, Andi Mappasala said: 'As agriculture production is being developed, a rising number of farmers have been able to purchase tractors. But they find that, after using them for a year, it becomes much more expensive than they expected because they have to spend a tremendous amount of money on spare parts. Perhaps we might recommend that Indonesia establish a factory that makes these spare parts, before they continue encouraging introduction of tractors in agriculture. For this reason a number of loans that government has been providing for farmers to modernise these agricultural techniques, particularly buying tractors, have not been paid back. If the tractors were still running they could probably pay back their loans. In fact, these tractors are becoming a problem themselves, because they sit around getting rusty and thus turning into pollution.'

What are the ways in which export businesses have been developed in Third World countries? In general, there are three main methods: direct sales, sales through an agent or distributor, and the creation of a local subsidy complete with local partner. There are no firm rules in businesses as to which method to follow. So much depends on the current economic political and legal circumstances, the policies, objectives and conditions of the particular company and judgement. Some practical guidelines on exporting to developing countries have been given by Thorneloe (1985).

Direct sales often is the simplest and least costly in terms of local expenses in the exporting country, *provided* that problems do not arise. Selling through an agency or distributor has become, in many countries, the most common technique used by British companies. The use of commercial agents maintains regular market pressure. It provides a basis for after-sales service which has been of growing importance in the 80s as owners seek to keep their purchases working for longer periods. A local agent can also assist in bidding for certain Government contracts; local subsidiaries; political stability of the area; suitability and integrity of local commercial partners; longer-term sales potential; financial arrangements — especially the ability of the customer to pay; raw material supply; local artisan and management skills and the strategic location in terms of selling in other regions.

Since 1967 the United Nations Industrial Development Organisation (UNIDO) has adhered to its mandate 'to promote and accelerate the industrialisation of the developing countries.' The Lima Declaration was adopted at a UNIDO conference in 1975 calling for an international effort to increase the developing countries' share of world industrial production to 25% by the year 2000. This goal was further emphasised at a UNIDO conference in New Delhi in 1980.

The agricultural machinery industry is seen as special because it offers a wide choice of technologies appropriate to local circumstances. It also relates directly to agriculture, the predominant component of most developing countries' economies.

UNIDO has established a programme in the field of agricultural machinery based on short term assistance. In Africa, UNIDO has been instrumental in developing a national agricultural machinery network for Algeria. UNIDO experience in this field is based on the setting up in 1977 of such a network in Asia and the Pacific in collaboration with FAO and ESCAP.

The import/export imbalance for Third World economies (The Agricultural Machinery Industry, 1983) is given in tables 8 and 9. Despite the UNIDO initiatives and the call for local industrial partnership from the Malaysian Prime Minister, many Third World countries are unlikely in the foreseeable future to be able to include an agricultural engineering manufacturing industry in their national or regional development programmes. As a consequence, there will be a continuing need for finished agricultural engineering products to be imported by countries of the Third World either on a North-South or South-South basis. Since the 60s the emphasis has been with North-South arrangements which in the 90s are likely to come under increasing pressure from preferential trade and tariff concessions being developed under South-South agreements. The 'Group of 77' developing countries met in Belgrade in April 1988 to discuss this and to reach new agreements. The accord is intended to create a regime under which tariffs can be removed or decreased for specific lists of products exchanged between member countries. The global system of trade preferences (GSTP) is intended to add a new dimension to world trade alongside existing blocs and regimes such as the General Agreement on Tariffs and Trade (GATT), the European Economic Community (EEC) and the Soviet-

Table 8 Percentage distribution of exports of agricultural machinery by regions 1971-1980

Regions	1971	1975	1980
Developed market economies	79.1	80.8	77.2
Centrally planned economies	20.3	18.0	20.9
Third World economies	0.5	1.2	1.9

Table 9 Percentage distribution of imports of agricultural machinery by regions 1971-1980

Regions	1971	1975	1980
Developed market economies	58.6	54.5	57.5
Centrally planned economies	17.8	17.0	17.5
Third World economies	23.6	28.5	25.1

led trade block COMECON.

The Yugoslav Trade Minister noted in an opening statement that the Third World today accounts for only five to six per cent of world trade and, due to a general economic development crisis, Third World trade growth had slowed in recent years. The new trade regime is intended to boost self-reliance and lead to structural changes in the existing world economic order. It is likely that under-developed industry, technological lags, the debt burden, unemployment, famine and other handicaps are likely to hold back the implementation of GSTP. The agreement will, however, promote further negotiations on long-term industrial co-operation, technology transfer and joint ventures among member nations.

The Yugoslav Trade Minister concluded by saying that 'without this particular arrangement ... the developing countries would not be able to speed up their development nor could they reduce the gap between the developing and developed world.'

Trade in agricultural products across the world tripled between 1950 and 1970. Since 1970 it has doubled. When it comes to farming, however, nations are at their most conservative, continuing to think mainly in local, national or perhaps regional terms and concerned above all, to protect their own farmers at the expense of competitors.

The World Commission on Environment and Development suggest that: 'shifting food production towards food deficit countries will require a major change in trading patterns. Countries must recognise that all parties lose through protectionist barriers, which reduce trade in food products in which some nations may have genuine advantage. They must begin by re-designing their trade, tax and incentive systems using criteria that include ecological and economic sustainability and international comparative advantage.'

7 Agricultural engineering and future Third World development

Clearly, agricultural engineering has made many important contributions to Third World developments in the past 50 years. It is equally clear that, as a discipline and a group of professional people, it has considerable potential to make further contributions in the future. Some of these will be an extension of what has gone on in the past, some will require new ground to be broken by agricultural engineers, some will demand new partnerships to be formed and some will arise because of new opportunities coming forward. All will need continued commitment and dedication to the urgent problems of food production, economic viability and sensitivity towards social, cultural and environmental issues. Agricultural engineers will need to take account of religious aspects in the course of their work. This is particularly important in the 42 Islamic Third World countries.

Training and management in the agricultural engineering disciplines will depend fundamentally on direction and priorities within the broader Third World issues. Perhaps the most important of these is the overall economic outlook for the world, and in particular, the Third World debt.

Countries in the north and south differ in their assessment of the situation. Key industrial nations are taking a generally optimistic view of short-term prospects for economic growth, international trade, financial imbalances and exchange rate stability. Finance ministers from Africa, Asia and Latin America are continuing to press the case for increased efforts by industrial nations to adjust their own economies, reduce protectionist barriers and restore financial flows to Third World debtors and other developing countries. This, they argue, should be done at levels required to achieve adequate growth and expansion of the economies on a technology input/market basis. The case from the developing nations is that there is no other way out of the debt problem unless debtors were helped to achieve adjustment with growth through a reversal of present net transfers of resources from poor to rich countries and a reduction of the Third World debt which currently stands at \$1200 billion (\$1.2 x 10^{12}). The future challenge for agricultural engineers in the Third World is therefore to seek and apply all means of making effective contributions to rural needs, especially agriculture; to place this work in the context of national and international activities so that priorities for its support might be raised; to perform and deliver in such a way as to fully satisfy needs, thus further improving priorities for support.

To do this, agricultural engineering teaching and extension must be relevant and of the highest standard; research and development must be appropriate, innovative and closely linked to practice; technology must be reliable, cost-effective and practical; above all, technology must be available through competitive commercial outlets operating in a stable economic environment.

If all of this can be achieved, then agricultural engineers will be providing valuable assistance to the generation of wealth and the quality of life in the rural sector. They will work in a priority position which has been earned amongst those professionals focusing on methods of reducing poverty, removing drudgery and meeting food security while helping to attain sustainable reduction in Third World Debt.

References

African Women: The step from subsistence peasant to subsistence farmer (1987). *World Farmers Times*. No.4.

Ahmed I, Kinsey B G. *(eds)* 1984. Farm equipment innovations in eastern and central Southern Africa, Gower Publishing Co, Vermont.

Allen Charles *(ed)* (1979). *Tales from the dark continent.* Futura Publications.

Bell R D, Johnson I (1986). Establishing priorities for research and development of agricultural machinery in developing countries. *Proc of Internat Conf on Small Farm Equipment for Developing Countries: Past Experiences and Future Priorities.* IRRI, Philippines.

Bonner T G (1979). Universities and overseas development. *Overseas Universities 26*, IUC publication.

Boutzev C, Faye S (1987). Reflections on engineering education in developing countries. *Internat J for Development Technology*, 5 (1).

Caldecote Lord (1984). The role of engineers in society: the use of resources and technology in the interest of mankind. *Australian Academy of Technological Sciences.*

Carter R C, Kay M G, Carr M K V (1986). Manpower planning for irrigation in sub-Saharan Africa. *Proc Inst Civ Engrs Part 1*, 80.

Centre for Science and Environment (1985). The state of India's environment 1984-85, New Delhi.

Chinsuwan and Cochran (1986). The axial flow pump in Thailand. *Proc Internat Conf on Small Farm Equipment for Developing Countries; Past Experiences and Future Priorities.* IRRI, Philippines.

Coffee R A (1981). Electrodynamic crop spraying. *Outlook on Agriculture*, 10 (7).

Constaninesco I (1962) Research and development towards improved farm implements for peasant farmers in the tropics. *The Agricultural Engineer*, 18 (4).

Cox S R W (1984). 60 Years of Agricultural Engineering NIAE 1924-1984. *National Institute of Agricultural Engineering J.*

Crossley C P (1984). Tillage requirements in relation to soil type in semi-arid rainfed agriculture. *J Agric Engng Res*, 30.

Deudney D, Flavin C (1983). *Renewable energy. The power to choose.* W W Norton, London.

Euphrates Irrigation Project (1981). *Middle East Agribusiness*, 1 (1).

Gego Arno (1986). Problems of agricultural mechanisation in Developing Countries. *Agricultural Mechanisation in Asia, Africa and Latin America*, 17 (1).

Goldemberg *et al* (1985). Ethanol fuel: A use of biomass energy in Brazil. *Ambio*, 14.

Hoffen (1960). Farm Implements for arid and tropical regions, FAO.

Hudson N W (1980). Soil degredation and civilisation. *NCAE Occasional Paper No 9.*

Inns F M (1988). Economic independence through sustainable development. *Practical Development* (Newspaper of the Group for Sustainable Development).

Jones Sir Emrys (1975). The development of agriculture in Iran. Summary of the First Douglas Bomford Memorial Lecture. *The Agriculture Engineer*, 30 (2).

Khan A U (1986). The Asian axial-flow threshers. *Proc Internat Conf on Small Farm Equipment for Development Countries: Past Experiences and Future Priorities*, IRRI, Philippines.

Kilgour J (1978). Engineering for food production in developing countries — are small tractors appropriate? *The Agricultural Engineer*, 33 (2).

Lacey, Robert (1981). *The Kingdom*, Hutchinson.

Land Food and People (1984). FAO.

Lantin R M (1986). Mechanisation for rice in Japan and Korea. *Proc Internat Conf on Small Farm Equipment for Developing Countries: Past Experiences and Future Priorities.* IRRI, Philippines.

Latin American Panel on Postgraduate Education in Agricultural Engineering (1969). UNDP.

Manby T C D (1961). Measurement of tractor and farm machinery performance under tropical agricultural conditions. *Cong Internat Technique du Mechanism Agricole.*

Matthews G A (1986). Pest control equipment for small-scale farmers. *Proc Internat Conf on Small Farm Equipment for Developing Countries: Past Experiences and Future Priorities*, IRRI, Philippines.

May B A (1979). Professional manpower: efficient use of resources: implications for the agricultural engineer. *The Agricultural Engineer*, 34, (3).

May B A (1985). Presidential address — 'Engineering for tomorrow's agriculture: the need for partnership and the management of change. *The Agricultural Engineer*, 40, (3).

May B A (1988). British education and training in international agricultural development. *Education and Training Supplement to Agriculture International.*

McRobie G (1982). Small is possible. *Abacus.*

Moens Prof Ir A (1983). Introduction to Agricultural Engineering at the Agricultural University Wageningen.

Mohan C (1986). Establishment of the tractor industry in India. *Proc Internat Conf on Small Farm Equipment for Developing Countries: Past Experiences and Future Priorities.* IRRI, Philippines.

Muzinger P (1982). Development and situation of animal traction in Africa and conditions limiting further promotion. *Animal Traction in Africa.* GTZ publication.

North-South: A programme for survival (1980). *Pan World Affairs.*

Nwa E U (1982). Development and programmes of Agricultural Engineering in Nigerian Universities. *Transaction ASAE.*

Our common future: The World Commission on Environment and Development (1987). Oxford University Press.

Partners in Development (1969). Praeger Publishers.

Pascoe R (1985). Biological results obtained with the hand held 'Electrodyn' spraying system. *BCPC Monogram No. 28*, Symposium on Application and Biology.

Payne P C J (1962). The Work of the National College of Agricultural Engineering. *The Agricultural Engineer*, 18 (4).

Photovoltaic technology for development (1986). UNDP

Proceedings of a Conf on Higher Education in Africa (1967). FAO.

Proceedings of a conference on the Human Environment (1972). UN Publication.

Rae G H (1985). Towards safer methods of pesticides application. *Conference on Pesticides in the Third World.* Organisers: Oxfam, British

Agrochemical Assocn and the Soc. of Chemical Industry.

Ramphal Sir Shridath (1979). Commonwealth Secretary General: Keynote address to Jamaica conference of Vice-chancellors of IUC associated universities.

Rijk A G (1986). The role of farm mechanisation in developing countries: experiences in Asian countries. *Proc Internat Conf on Small Farm Equipment for Developing Countries: Past Experiences and Future Priorities.* IRRI, Philippines.

Schumacher E F (1974). Small is beautiful. *Abacus.*

Shifting cultivation and soil conservation in Africa (1974). *Soils Bulletin,* 24, FAO.

Sims Prof (1980). The British Government's policy on university funding. *The Assocn of Commonwealth Universities Bulletin of Current Documentation,* No. 42.

Singh K N (1978). Agricultural mechanisation in India. *Proc Internat Agricultural Machinery Workshop,* IRRI, Philippines.

Smith R K (1988). 'The Electrodyn' sprayer. Matching the technology to contrasting areas of smallholder agriculture. *Chemistry and Industry,* 6, 196–199.

Soil conservation and management in developing countries (1977). *Soils Bulletin,* 24, FAO.

Starkey P (1988). Animal wheeled tool-carriers: a case for caution. ITDG publication.

Suri M M (1978). Agricultural mechanisation in India. *Proc Internat Agricultural Machinery Workshop,* IRRI, Philippines.

The Agricultural Machinery Industry (1983). An appraisal of the current global situation, production and market outlook. *Sectoral Studies Series,* No 5, I and II.

The Government's Expenditure Plans 1988/89 to 1990/91. *Cm 288, I and II,* HMSO.

Thorneloe J (1985). Exporting successfully. The Agricultural Engineer, 40 (3).

Tools for Agriculture (1987). ITDG.

Wan Hequn (1987). Study of the development of agricultural mechanisation in China. *J Beijing Agricultural University English Edition,* 1.

Wang Mao-hua (1986). The recent development of agricultural engineering science and education in China and the prospects to promote international collaboration. *Beijing Agricultural Engineering University.*

Willcocks T J (1984). Tillage requirements in relation to soil type in semi-arid rainfed agriculture. *J Agric Engng Res,* 30.

Worster Donald (1982). Dust bowl: the Southern plains in the 1930s. Oxford University Press.

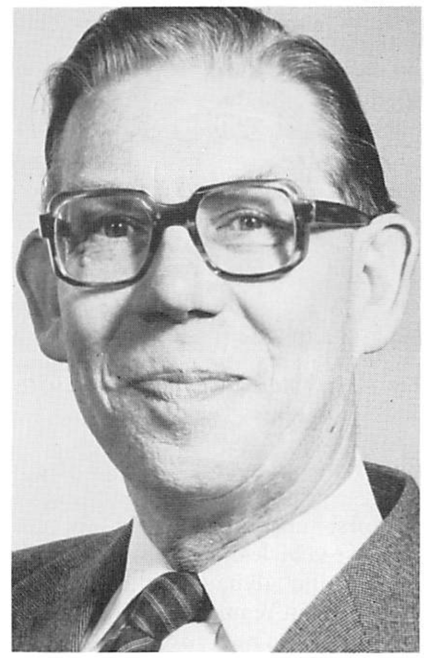
World Resources Institute/International Institute for Environment and Development (1987). *World Resources.* Basic Books, New York.

Instrumentation in Agricultural Engineering

S W R Cox and M E Moncaster

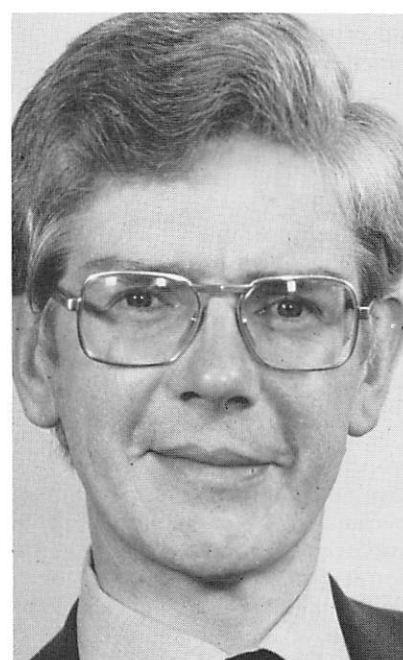
Summary

THE progress of instrumentation for agricultural engineering research, development and testing over the past 50 years is reviewed, together with the growth of instrumentation for agricultural monitoring and control systems in the same period. The important part played by developing electronics and computer technology in information gathering and processing is emphasised. The future direction of development in all of the above spheres is considered, within the framework of advances in information engineering.



Sidney Cox

Michael Moncaster



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1 Introduction

In 1938 instrumentation in agriculture and horticulture was mostly simple and its function was solely to provide information on which the farmer or grower could act. Instrumentation as the input to automatic control systems would have been hard to find. Farmers and growers employed traditional mechanical weighers, thermometers and — to a lesser extent — hygrometers in and around buildings, while simple gauges served on farm tractors.

In fact many of these measuring and indicating devices held sway until comparatively recent times in agricultural and horticultural enterprises. However, the requirements of research, development and testing in the agricultural engineering sphere led to a much earlier diversification and sophistication of instrumentation systems. These have served not only to improve the design and use of agricultural and horticultural machines and buildings but also to foster the development of automatic control of machines and buildings environment.

This paper therefore begins with a brief survey of the development of instrumentation for R & D and testing over the past fifty years before outlining the development of agricultural and horticultural monitoring and control systems. The final section deals with the likely pattern of development in both of these spheres, viewed as an essential element in the growth of information engineering.

2 Instrumentation for R & D and testing

2.1 Field machinery and equipment

Pre-war field testing of tractors in the UK, sponsored by the RASE (Cashmore, 1985) called for measurements of engine power (*via* belt tests), drawbar power and fuel consumption, *inter alia.* Post-war, the NIAE tractor test scheme was launched (Cox, 1984). This soon led to drawbar testing on tarmac roads and thence to the establishment of national and international test codes.

Hydraulic instrumentation was developed for these tests and for research into all aspects of field machinery design and operation. The commercial manufacture of drawbar dynamometers by Roadless Traction Ltd. was noted in the NIAE/SMTS Report for 1949–51 (BSRAE 1952). These (fig 1) had ranges up to 10,000 lb — subsequently extended by NIAE to 40,000 lbs. (Hamblin *et al*, 1954). The report also cited the development of an hydraulic pto dynamometer (Raybould and Nation, 1950).

Use of these devices continued for many years but in the same report there is reference to an "elaborate" 8-channel chart recording apparatus and mobile laboratory for use with strain gauge dynamometers. The equipment was employed for measurements of the forces acting on plough bodies (Hawkins and Rogers, 1950) and the draught of mounted implements, in particular. A strain gauge torque/speed meter with a span of 18 to 2500 rev/min had also been developed for use with the system. This instrumentation was the

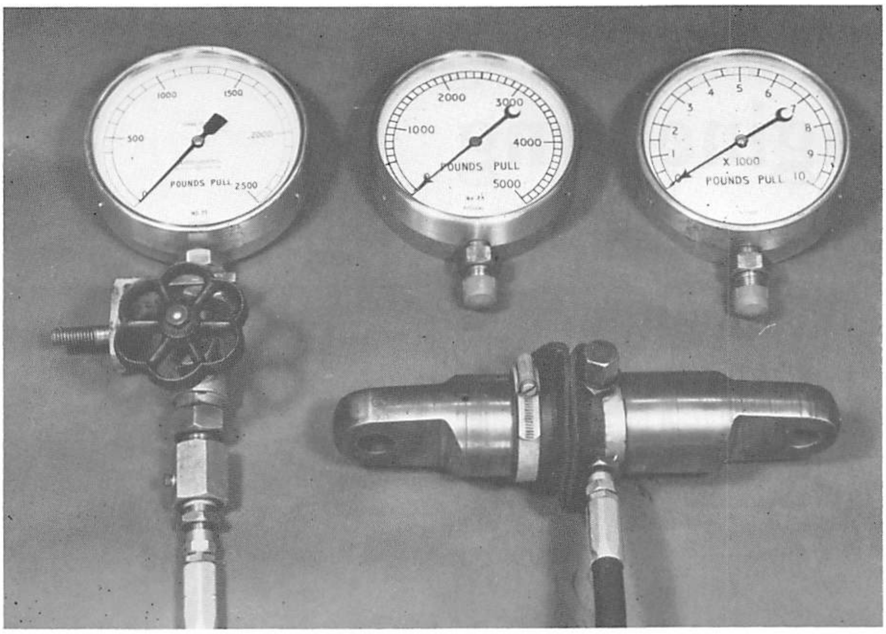


Fig 1 Hydraulic dynamometer (1950s) (AFRC Engineering)

forerunner of many forms of strain gauge equipment for field testing of tractors, implements and special-purpose vehicles such as single-wheel testers and dynamometer loading cars, now in regular use.

Yet another development mentioned in the 1949–51 report was a mobile weighbridge, with mechanical steelyard weighers, for measurements of harvester output and other tasks involving vehicle or trailer weighing (Hamblin, 1951). This led to the design of models up to 8 t capacity (Filby, 1969), employing matched strain gauge load-cells, with outputs that could be summed electrically. Although axle weighing with transportable mechanical or hydraulic weigh pads has retained a place in field testing, continual improvements in the accuracy, stability and reliability of strain-gauge load-cells have made them dominant in this sphere.

Measurements of important soil properties in the engineering context have an equally long history. Simple mechanical testers continue to be employed but some — such as the penetrometer — have been "automated" (O'Sullivan *et al*, 1983) to improve the rate and accuracy of data gathering. Measurements of soil density in connection with compaction (a problem recognised in the NIAE/SMTS report cited earlier) gave rise to the gamma ray attenuation meter in a variety of forms, including the SIAE twin-probe meter for mapping density/depth profiles. (Henshall and Campbell, 1983). Another radioactivity-based meter — the neutron moderation soil moisture meter — is also well established.

Post-war mechanisation of field operations soon led to concern for the welfare of the tractor and combine driver. By 1960 it was apparent that reduction of machinery noise and vibration (particularly ride vibration) required urgent attention. The ensuing research depended on high quality sound level meters and accelerometers (inductive and capacitative) respectively (fig 2) (Cox, 1964; Simons, 1964). These were coupled to analogue recorders and frequency analysers for studies of the origins and likely physiological effects of the noise and vibration. At the same time, the alarming statistics on tractor overturn accidents led to research on safety cab design involving photographic techniques as well as accelerometer measurement (Manby, 1964). Research on ride vibration also provided applications for the analogue computer in the 1960s (Matthews, 1964–1966).

Fig 2 (a) Noise and vibration measurement (1960s): noise measurement at the operator's head position (AFRC Engineering)

Ergonomics and field testing have provided many examples of the evolution of signal recording and analysis equipment over the past forty years. The best available frequency response from the pen recorders used in the early 1950s was about 60 Hz (Filby, 1967). The ultraviolet recorders which appeared in the mid '60s made it possible to record signal components in the low kHz range but analysis from chart records remained time-consuming and tedious, despite the development of ingenious chart digitising aids (Matthews, 1967). Frequency-modulated magnetic tape recording made it possible to extend the working range into the higher kHz bands and to replay recorded signals (at multiples or sub-multiples of the recording speed, if required) into analogue frequency analysers. This could generate power/frequency spectra in minutes, rather than hours. The establishment of digital computer installations for data analysis led to the development of data loggers with computer-compatible, digital output on punched paper or magnetic tape but initially these were only useful for slowly varying or integrated values of measured quantities. However, the effect of microelectronics developments on computer design and operation has revolutionised signal processing and analysis over the past decade. For example a transportable Fast Fourier Transform Analyser can now average nearly 100 power spectra in a minute.

Thus, increasing speed and sophistication of instrumentation has made it possible to gather representative data on the performance of field equipment in varying conditions, in a short time, or — through rapid, in-field signal processing — to repeat or modify test runs while conditions are relatively unchanging.

Finally, the range of laboratory instrumentation associated with field

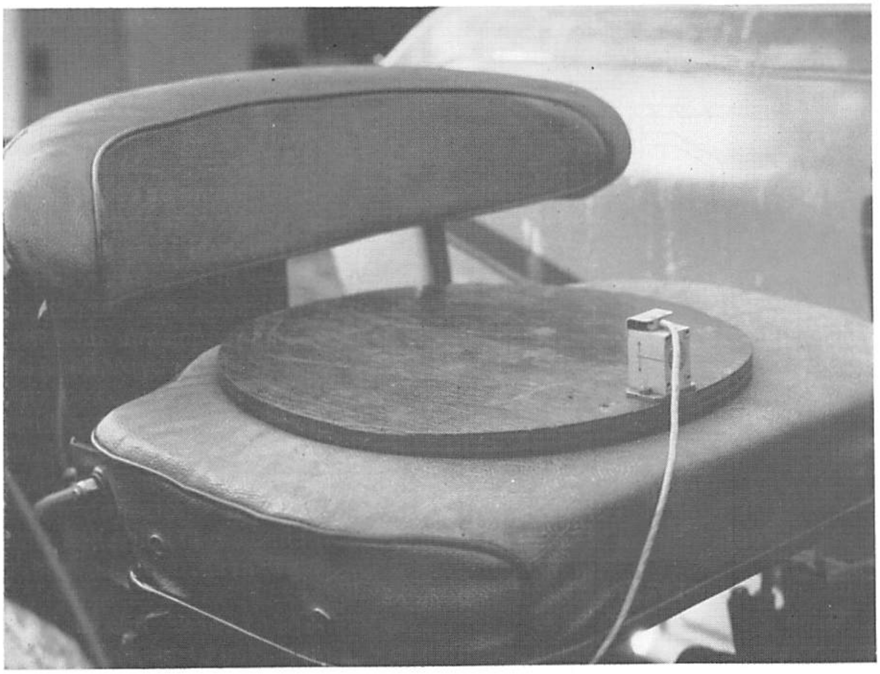


Fig 2 (b) Ride vibration: seat testing rig with accelerometer

testing cannot be ignored. This embraces materials testing and analysis equipment in many familiar industrial forms but special equipment has also been devised for particular agricultural operations. The pendulum installation for determination of the centre of gravity of tractors and the semi-automatic recording of spray patternator deposits (fig 3) are two examples.

2.2 Buildings structure and environment

Research on glasshouse design and performance was well established in the early 1950s, with measurements of air temperature and humidity, carbon dioxide concentration (to monitor air movement), solar radiation intensity and other meteorological quantities. (BSRAE, 1952).

Pen-type thermographs and thermohygrographs, based on expansion and contraction of temperature and humidity sensitive materials, were commonly employed and were placed in the thermal screens needed to protect them from the heating effect of solar radiation (fig. 4a). Temperature integrating jars were devised as a simple, inexpensive method of mapping mean night-time temperature distributions in the cropping zone. Essentially, the thermal mass of a standard mercury-in-glass thermometer was increased by surrounding the bulb and lower stem in a 2 lb preserving jar filled with water and wrapped with reflecting foil to reduce radiation effects. (Winspear and Morris, 1959). At the other extreme, expensive infrared analysers were needed for CO_2 monitoring. Studies of greenhouse light transmission to determine optimal shape, structure and orientation — which still continue — have made use of a variety of photometric and radiometric devices, of which the best known is the Kipp solarimeter. This instrument employs an array of thermocouples to sense the rise in temperature of a blackened disc which is exposed to solar radiation from a complete hemisphere.

More recent research into control of aerial and root zone environment in heated greenhouses has involved measurement of heat input and analysis of nutrient levels in plant

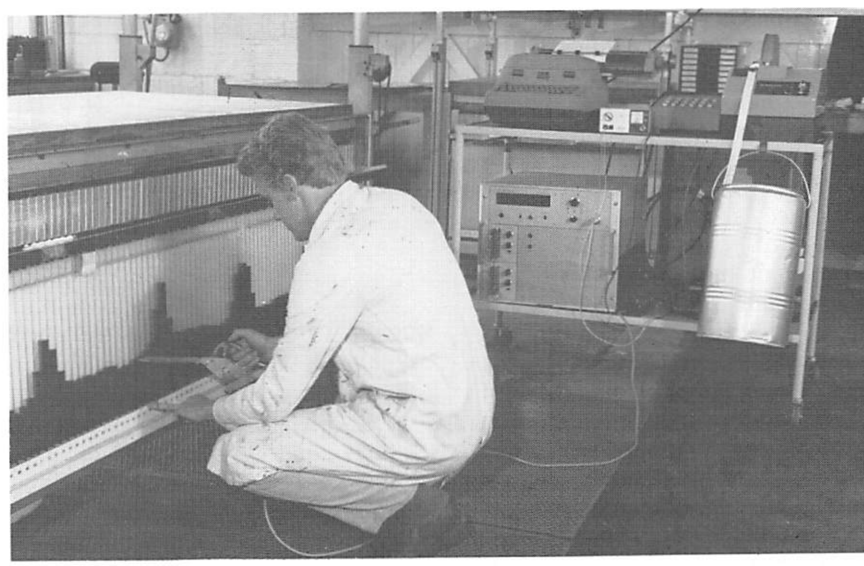
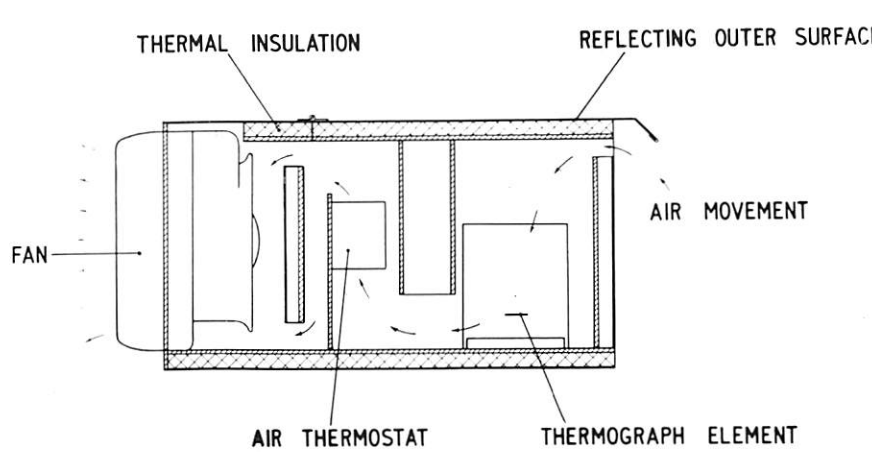


Fig 3 Spray patternator, with recording calliper and data logger (AFRC Engineering)

Fig 4 (a) Greenhouse aspirated screens 1960s (AFRC Engineering)



feed. Heat input can be determined by measuring the inflow and return water temperatures in the heating pipe circuits combined with the rate of water flow, using a suitable flowmeter (Bailey, 1975). Electrochemical, ion-selective sensors are being evaluated for monitoring individual nutrients in nutrient film systems. (Winsor *et al*, 1979). Aerial and root zone temperatures are now routinely measured with high grade electrical resistance thermometers (usually platinum) in view of the close control of environment demanded in greenhouses. RH sensors are usually of the wet and dry bulb type, with platinum resistance thermometers, for accuracy and reliability (fig 4b).

The establishment of codes of practice for farm buildings construction led initially to research on wind loading of glasshouses, starting in the 1970s. Special wind pressure sensors and mobile instrumentation (figure 5 a and b) were developed for this work, which was subsequently extended to film plastic structures and farm buildings generally (Moran, 1980).

Research on other farm buildings was slower to develop than in the glasshouse sector but extensive studies of livestock buildings environment have been in progress since the late 1960s. One common feature of this work has been measurement of low-rate airflow by various means, including the use of photographic recording to map the movement of small, uniform soap bubbles in the air currents (fig. 6). Ion-selective sensors have made a recent appearance in this sphere, for monitoring of ammonia concentrations in poultry houses.

2.3 Handling and processing of crops and animal products

Air temperature, humidity and flow measurement in driers and crop stores has been a feature of R & D and testing over fifty years. Thermocouples, with attendant ice-point reference vacuum flasks and indicating microammeters or multi-point chart recorders, were common for many years, as in other areas of environmental measurement. In fact, thermocouples have held their place for multi-point temperature monitoring, and are now in association with electronic instrumentation which automatically scans the sensors, provides the reference point and applies calibration and linearisation corrections.

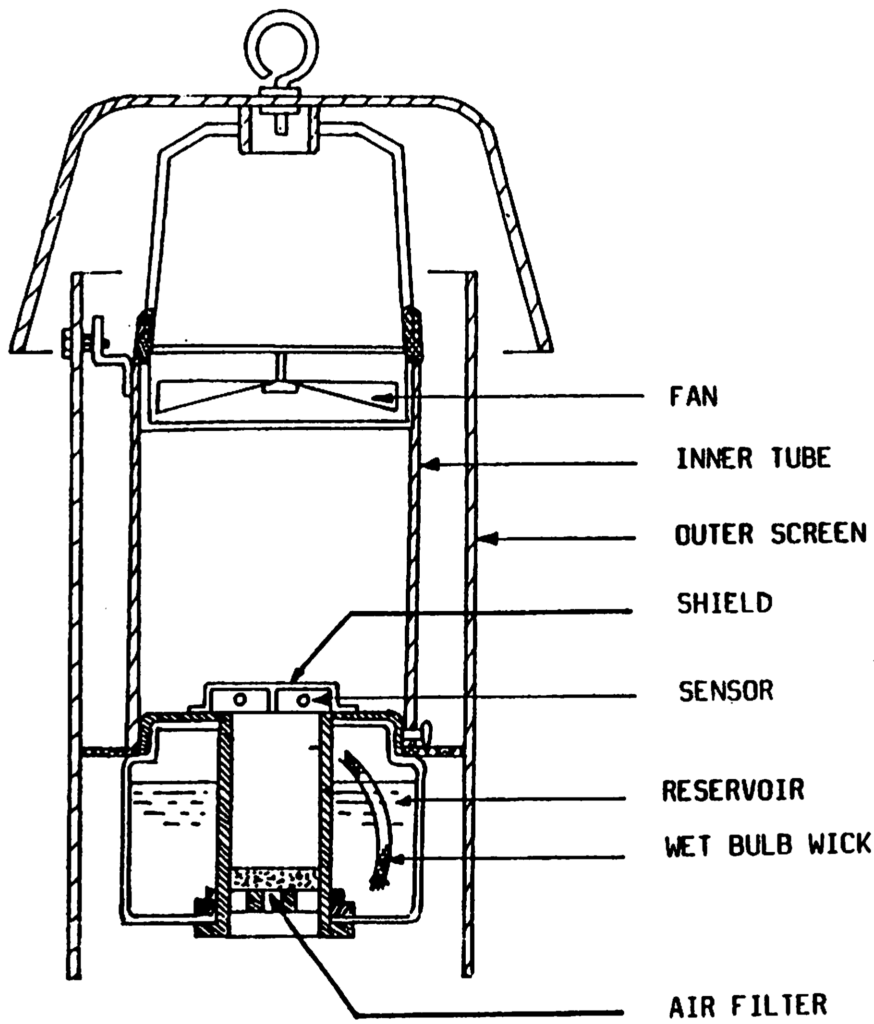


Fig 4 (b) Greenhouse aspirated screens 1980s (Victor Automation Systems)

The measurement of relative humidity is always difficult and still largely remains the domain of wet and dry bulb hygrometers, despite developments in electrical RH sensors from the early 1950s. However, the latest industrial dewpoint meters — although expensive — are finding application because of their ability to tolerate a moderate level of contaminants in the monitored atmosphere.

Crop drying introduces another difficult measurement, namely determination of crop moisture content. Many forms of standard oven determination have evolved over the past fifty years, for specific purposes. However, the advantages of a portable meter for on-farm testing led to the early adoption of the Marconi moisture meter in the UK. This meter (measuring the electrical conductivity of a milled, compressed grain sample) was tested at NIAE (BSRAE, 1948) and remained a working standard for many years.

Crop handling and processing operations such as feed milling and mixing, sorting and grading have given rise to several tracer techniques. Fluorescent tracers, introduced in the1950s for studies of spray deposits, were also used in testing of feed mixers. Studies of the performance of operators on fruit grading lines of different designs made use of artificial apples with simulated visual defects and corresponding, invisible codings. Coding was provided by internal ferrous material of several sizes and the hidden code was determined via detector coils placed at the discharge points along the line. (Harries and Gale, 1968). In this way the operators' performance was monitored automatically. Simulated apples, potatoes and other produce have also been developed for studies of damage risk in handling installations. These objects contain

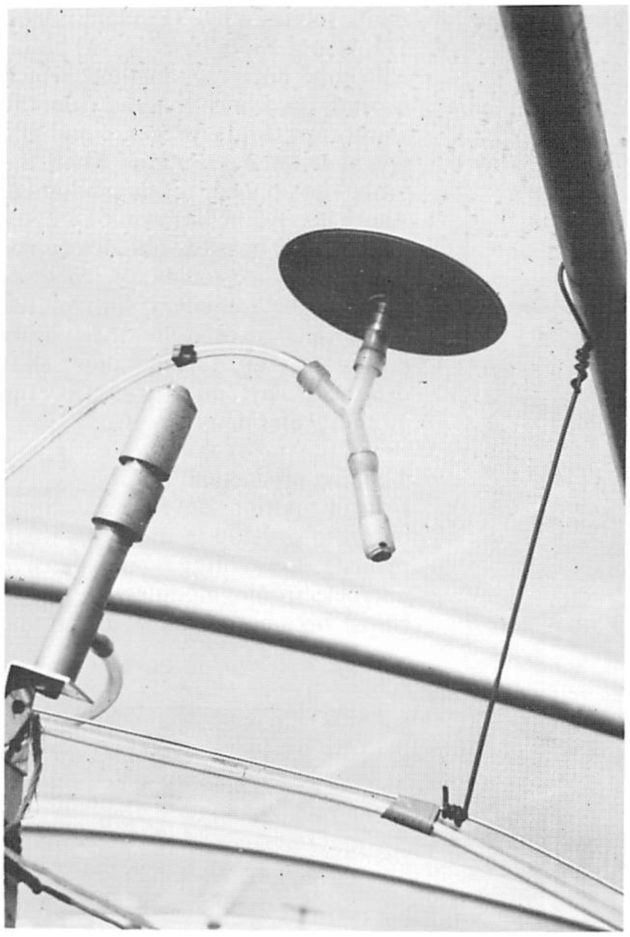
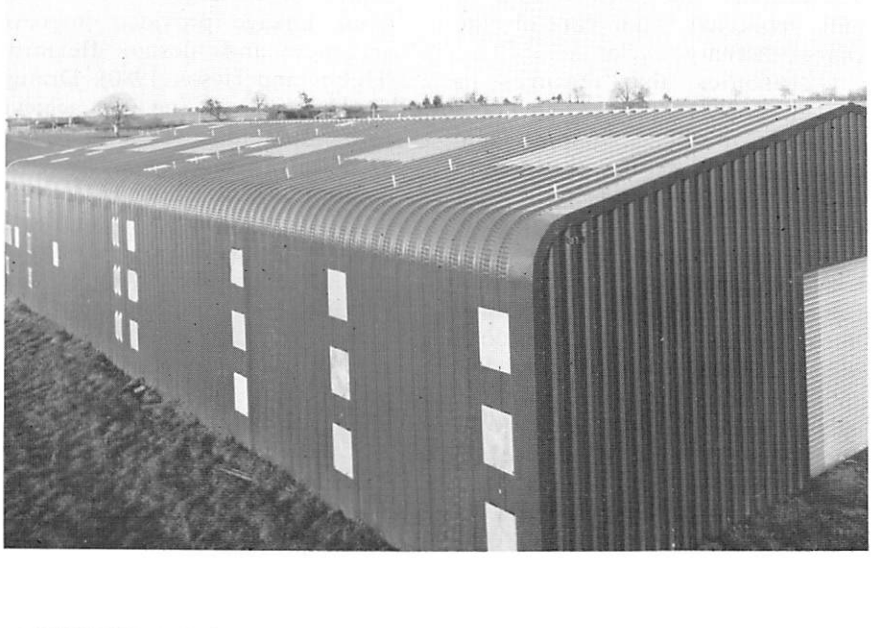


Fig 5 (a) Wind loading instrumentation (AFRC Engineering) Wind pressure sensors for farm buildings (left) and film plastic houses (disc in centre) showing plastic tubes which transmit the wind loading to the instrumentation trolley

internal pressure or acceleration sensors coupled to a telemetry unit which transmits the measured data.

In the livestock sector, development and testing of milking equipment also has a long history. In the UK the key role played by the National Institute for Research in Dairying over many years (Thiel and Dodd, 1977) has now passed to the Milking and Mastitis Centre, AFRC Institute for Animal Health. NIRD built up vacuum and pressure monitoring facilities for studies of the effects of machine milking on milk let-down and on animal health. These involved monitoring of conditions in the milking cluster, in addition to the widely employed measurements of airflow and vacuum cycles in the pipelines, which form part of standard testing procedures.

Fig 5 (b) Farm building with sensor array



Testing of parlour milk meters required the establishment of controlled flow facilities (Hoyle, 1965). More recently (Anon, 1980) the Milk Marketing Board set up a computer-controlled calibration rig for the turbine flowmeters fitted to bulk milk tankers. Payments to the farmer are based on the readings of these meters.

3 Instrumentation for agriculture and horticulture

Instrumentation for on-farm use must be robust and reliable in an often hostile environment; simple to operate and easy to check or service (Cox, 1988). Normally it must be inexpensive. Fortunately, accuracies of better than ±2 or 3% are not often needed.

3.1 Livestock production

Environmental control in livestock buildings developed with post-war intensive production and the resulting research on ventilation that began in the 1960s (Owen, 1967; Cox, 1984). Today's electronic ventilation controller is frequently based on temperature monitoring thermistor arrays (Cox, 1988). Monitoring with hand-held temperature/RH meters and airflow meters is possible, as in crop stores. Young stock requirements are met by a variety of controlled heating systems, including the radiant heating equipment for young pigs and poultry which employs a "black body" radiation sensor with an internal semiconductor temperature-sensitive element, to simulate the requirements of the livestock.

Monitoring of animal performance now takes several well-established forms. Load cell weighing of feed inputs can be incorporated in granular and liquid feed installations for pipeline or conveyor distributions, while the consequent liveweight gain can be monitored with electronic weighers deriving from R & D in the 1970s (Smith and Turner, 1974). Semi-automatic techniques were devised for weighing pigs, beef and dairy cattle, using electronic integration to reduce the effect of animal movement. Fully automatic poultry weighing has also been achieved by coupling strain-gauged perches (fig 7) to a microcomputer, programmed

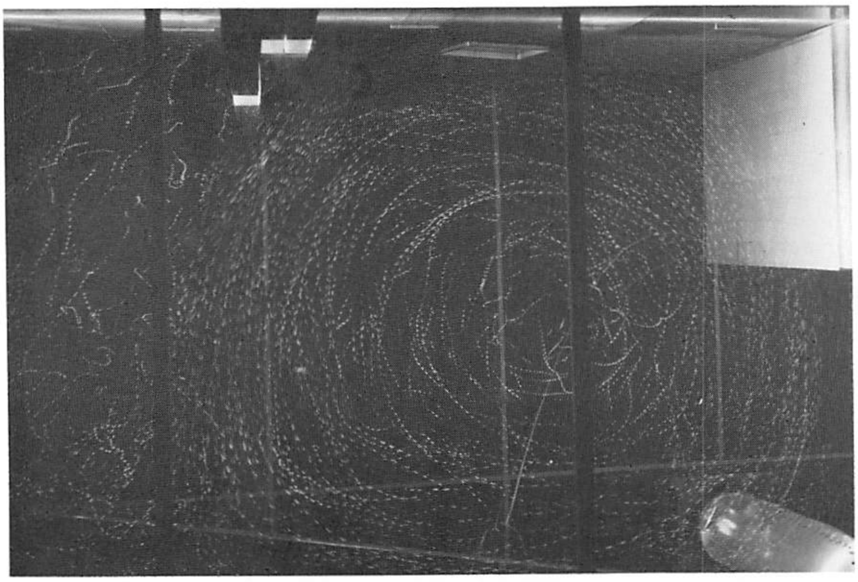


Fig 6 Airflow patterns in a simulated piggery (AFRC Engineering)

evolved in the 1960s (Lindahl, 1966). This is sometimes based on the pulse-echo time difference method, which depends on echoes received from the amniotic fluid present in the pregnant animal's uterus when the probe is applied to its abdomen. Alternatively, the ultrasonic Doppler method may be used. This detects the presence of a foetus or foetuses through the frequency shift of the echo signal caused by their heart pulsations, or through the shift produced by pulsations in the mother's uterine artery (Cox, 1988).

3.2 Crop production

Instrumentation on field machines began to develop in the 1970s when robust, low-voltage, inexpensive microelectronics modules (the silicon chips) became available. Electronic

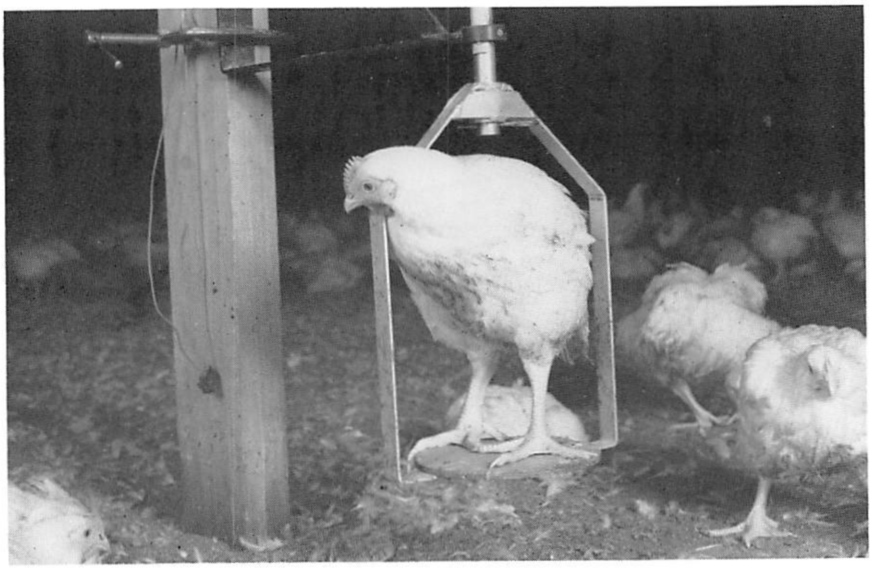


Fig 7 Electronic weighing of poultry (AFRC Engineering)

to reject suspect weight signals by reference to a running average of the bird's weights (Turner *et al*, 1984). Monitoring of sow feeding and of concentrate feeding to cows introduces the animal identification "transponder" or "responder" in its collar-borne or ear-tag form (Cox, 1988) through which each animal can gain access to its individual ration. They also owe their existence to R & D in the 1970s (Street, 1979).

Milk recording and automatic cluster removal (ACR) are now features of many dairy parlours, the ACR being actuated when milk flow from the cow concerned falls below a predetermined level for a set time. Milk flow is monitored via the accumulation of milk in a recording jar, from which it is transferred to the dairy's bulk tank at the end of the cow's milking, or by direct-to-line meters which collect and discharge the milk drawn from the cluster in small batches (typically, 200 ml) and count the number of batches in a cow's milking. Recorder jars can be supported on strain gauged beams to measure yield gravimetrically, or fitted with volumetric level sensors. The level sensors shown in fig 8a are water-filled steel probes with an internal ball-bearing, magnetically levitated by an external float. The position of the ball (ie the milk level) is determined by an ultrasonic pulse-echo sensor in the top of the probe. Figure 8b shows one type of direct-to-line meter, which has a metering chamber fitted with upper and lower electrical conductivity electrodes. These define the batch volume of milk collected and control the charge/discharge cycle.

Ultrasonics also features in instrumentation for *in vivo* measurement of back fat in pigs and pregnancy in several types of farm animal. Pulse-echo methods for determining the position of acoustic discontinuities between fat and lean tissue — and hence the thickness of fat and lean meat — were pioneered in the USA in the 1960s (Johnson *et al*, 1964). The piezoelectric ultrasonic transmitter/receiver, operating in the MHz range, must be acoustically coupled to the animal's back with suitable grease or oil. Experience is needed to operate this equipment but the method is now widely employed. Ultrasonic pregnancy detection also

control of the larger tractor's three-point linkage provided improved accuracy and design flexibility (Hobbs and Hesse, 1980). Draught and position sensing was achieved with simple inductive transducers (fig 9). This was followed by spray rate monitoring and control, based on measurement of forward (ground) speed and spray line pressure (fig 10), which reduces the effect of speed variations on application rate. Recently, active spray boom suspensions employing ultrasonic pulse-echo height sensors near the boom tips (Marchant and Frost, 1985) improved the uniformity of spray deposition.

Measurement of ground speed by simple magnetic sensors on an undriven wheel, or by the more

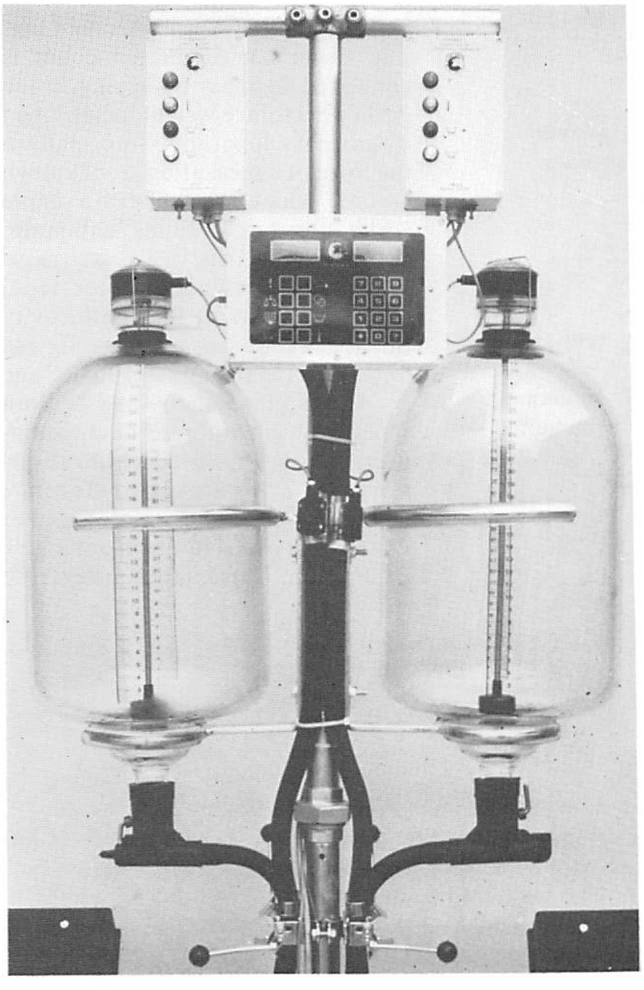


Fig 8 (a) Milk yield recording. Ultrasonic level sensors in jars (Pig & Cattle Code Ltd)

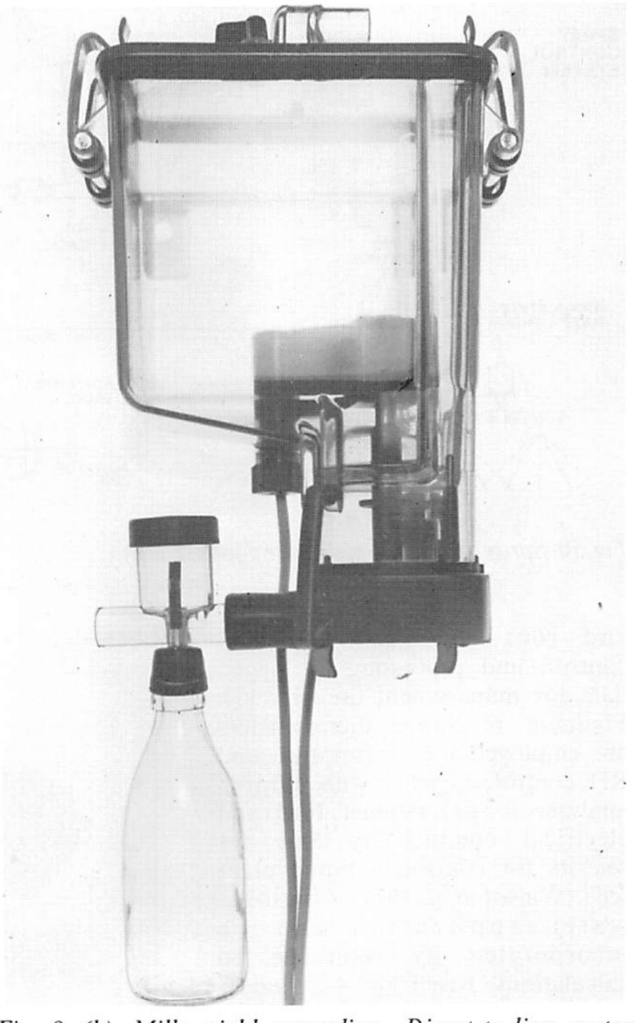
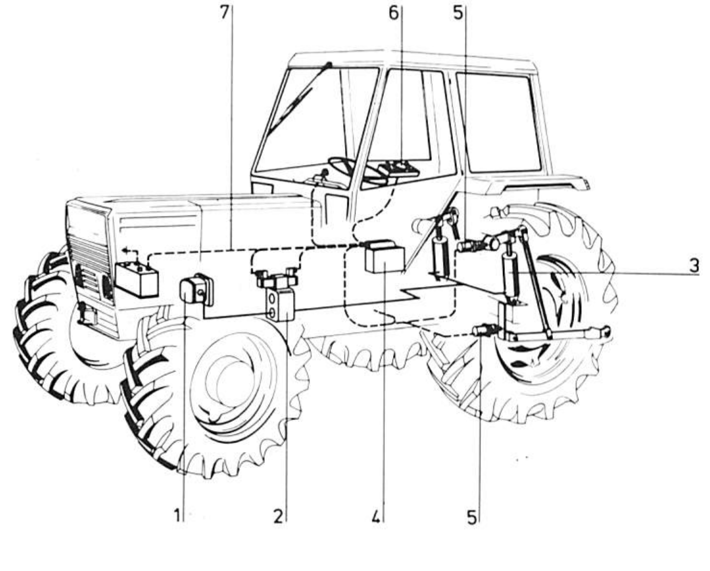


Fig 8 (b) Milk yield recording. Direct-to-line meter (Fullwood & Bland Ltd)

accurate but more expensive microwave Doppler speed meter (Sokol, 1984) is the basis for wheelslip control and for speed/area meters which provide valuable data for managers on field work rates. Some larger tractors now have extensive microcomputer-based facilities for tractor and implement monitoring, together with self-diagnostic features and the ability to calculate (and display) optimum machine settings, as an operator aid (Cox, 1988). Moves are also being made towards more standardised interfacing of in-cab monitors and implement sensors. The general-purpose monitor unit featured in figure 11, has a display controlled by "intelligent" sensors (i.e. sensors with built-in processing power). Data and commands flow between the monitor and the sensors via standard serial communications links.

Fig 9 Three-point linkage control (Robert Bosch). Sensors 5; control box 6; control valve 2



Similar monitoring features are now available on some combine harvesters in addition to the longer-established grain loss monitors which enable the driver to regulate ground speed in accordance with losses, and grain yield meters in volumetric or gravimetric form. Figure 12 shows a gravimetric sensor in the form of a sloping plate, supported on a strain-gauged beam, over which the grain flows from the discharge auger.

Crop production in heated greenhouses has led the way in the application of advanced monitoring and control systems in the agricultural and horticultural sector until very recently.

Centralised or distributed computer systems now exist on many larger enterprises; integrating meteorological monitoring, aerial

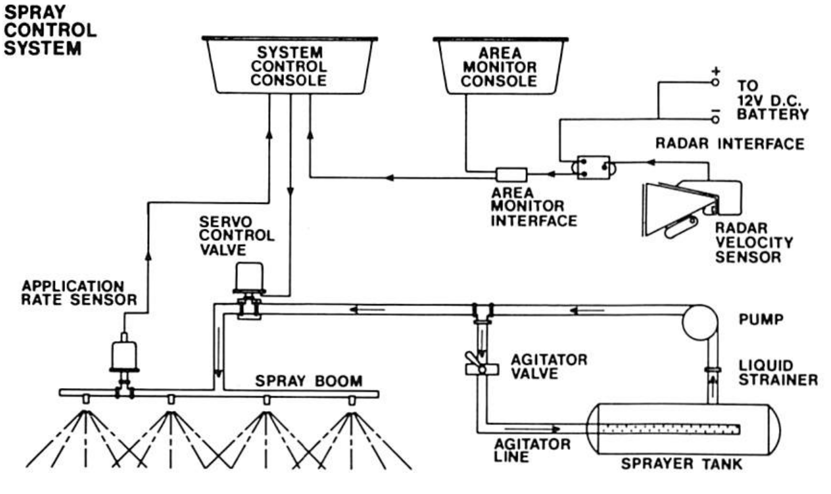


Fig 10 Spray rate control (Dickey-john Corp)

Fig 11 All purpose monitor with "intelligent sensors"

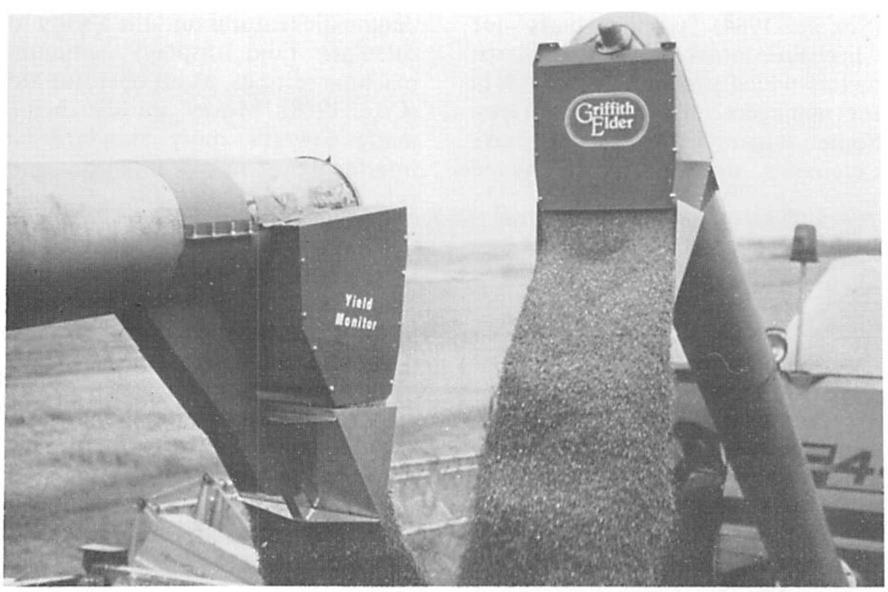


Fig 12 Combine harvester grain yield monitor (Griffith Elder Ltd)

and root zone environmental control, and processing of logged data for management use (fig. 13). Platinum resistance thermometers are employed for temperature and RH control, together with infrared analysers for CO_2 (Sanger, 1985) and electrical conductivity and pH sensors for control of liquid plant feed (Winsor *et al,* 1979). Control of water application can be incorporated by reference to calculations based on solarimeter outputs, or, where solid rooting media are employed, to capacitance moisture sensors, evaporimeters or porous pot tensiometers. The last-mentioned are instruments from which water is sucked as the surrounding soil dries, to create an internal vacuum which is employed to trigger water application and so to remove the water stress.

3.3 Post harvest operations

Monitoring of materials handling off the field and into or out of store has been greatly facilitated by the development of strain-gauge load cells with low sensitivity to temperature change and to the point of application of the load (Cox, 1988). These are the basis for a new generation of outdoor weighbridges and axle weighers; the latter enable the farmer to weigh trailer and lorry loads of produce, axle by axle, statically or on the move at speeds of up to about 3 km/h, with accuracies of ±0.5% full scale or even better.

For indoor grain handling installations a high rate (200 t/h) mass flowmeter akin to the yield meter in fig 12 is available, together with a volumetric meter for up to 60 t/h. The latter counts the revolutions of a motor-driven, constant speed paddle through which the grain is discharged. A constant load of grain is maintained with the aid of a level sensor to minimise bulk density variations in the paddle chamber. The meter's accumulated count is converted to mass by keying in the grain's hectolitre weight, determined by auxiliary apparatus — normally in the form of a measuring jar of known volume, which is weighed on a simple scales after careful filling with grain.

Crop drying and storage frequently involves electrical moisture meters of the conductivity or capacitance-sensing types (fig 14a and b) (Matthews. 1963a and b; ADAS, 1985; Cox, 1988). Both types now incorporate microcomputers with built-in calibrations derived from oven reference standards of various kinds, together with automatic temperature connection. Capacitance meters also incorporate automatic bulk density connection, in view of their sensitivity to variations in this quantity. Some also allow averaging of multiple measurements. The right-

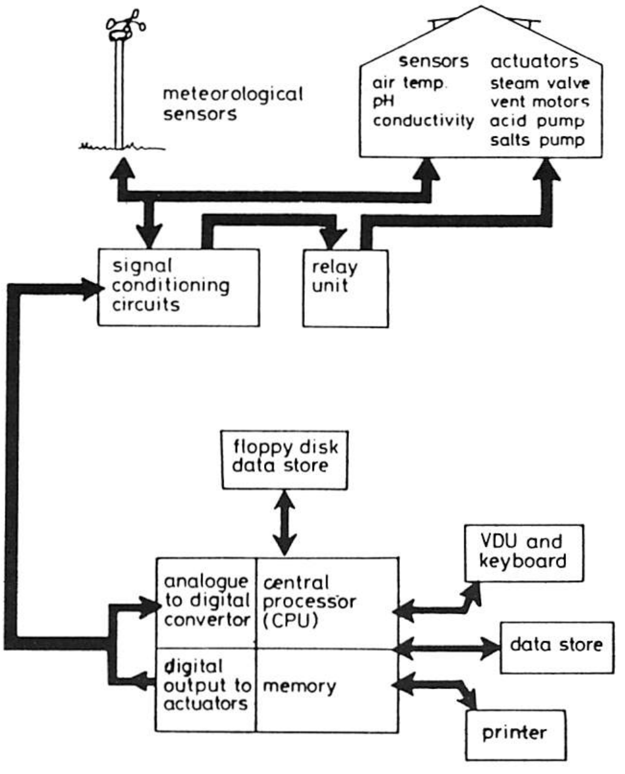


Fig 13 Greenhouse monitoring and control (AFRC Engineering)

rate colour/weight graders for tomatoes, fruit and other produce. Very recently this has been extended to size and colour grading based on video-cameras and advanced computer analysis, thereby introducing image processing techniques into farm electronics.

4 Future developments

As the previous sections have shown, the applications of instrumentation to agriculture and horticulture are very widespread indeed. Nevertheless, the size of the potential market for a specific instrument, sensor or control system is small compared with, for example, the domestic market. Also, the unit prices which are acceptable in these industries are modest compared with those for defence applications, for example. It follows that the development of instrumentation for the agricultural sector rests very heavily indeed upon developments in information engineering for applications in other sectors which are able to bear the costs of development and of equipping for the large production runs needed to achieve low unit costs.

Given the diversity of instrumentation already in use and the breadth of application, it is almost inevitable that the future developments will tend to be more of the same rather than developments in entirely new directions. Developments of integrated circuit techniques have already led to miniaturisation and CMOS chips permit very low power consumption. Thus, portable equipment is now feasible which would have been unthinkable only a few years ago.

hand instrument in fig 14a creates calibration tables for particular types of grain against selected oven standards. Its own readings are compared with the results of oven determinations on identical samples, keyed in by the user. The tables can then be down-loaded to a set of working instruments (one is shown on the left) *via* a serial communications link, to provide them with identical calibrations.

Crop storage also involves temperature and RH monitors in controlled ventilation installations using individual monitoring or comprehensive sensor scanning, data processing and control units. Portable, low range airflow meters are available for checking the ventilation rate in stored grain and other products.

Long-term sealed and refrigerated stores (controlled atmosphere or ultra-low oxygen stores) for fruit and other high value crops depend on paramagnetic oxygen meters and infrared CO_2 meters for control of their low O_2, high CO_2 atmospheres, as well as accurate resistance thermometers for temperature control. Hence this is another area for computer-based monitoring, control and data processing (Sharples and Jameson, 1984).

Quality grading of produce by operators has been facilitated by manual aids such as the hand-held "magic wand" developed by SIAE. This informs a computer of the location of defective produce on a conveyor line, for subsequent automatic removal of the produce (Carlow, 1983). Tapping an object on the conveyor with the "wand" energises a transmitter in the latter, and its position is located by a matrix of receiver coils under the conveyor. This system is in use for potato and egg grading. Another SIAE development — the X-ray absorption system for distinguishing potatoes from stones and clods (fig 15a) (Palmer *et al*, 1973) has also found application in potato grading installations. Automatic colour grading has advanced post-war from the early American developments (Nickerson, 1946) through high-speed seed cleaners (fig 15b) to high-

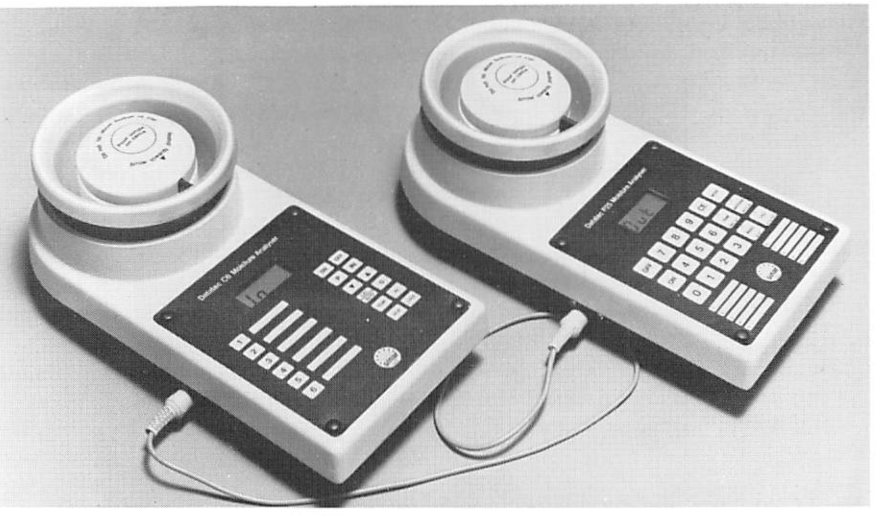


Fig 14 (a) Capacitance meters (master and slave) (SinarTechnology)

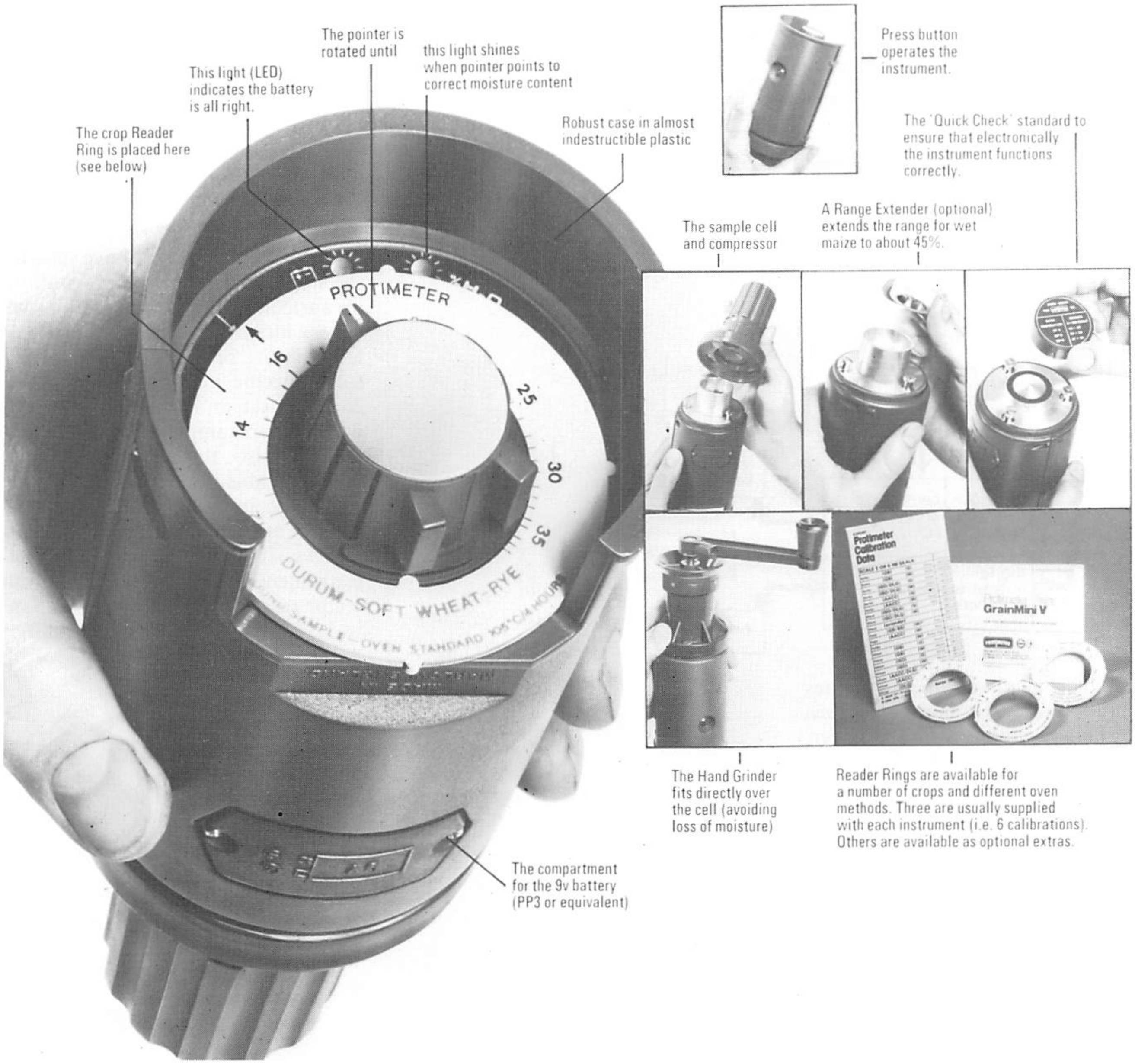


Fig 14 (b) Crop moisture meters conductivity meter (Protimeter plc)

However, the most striking development which has already begun to dominate instrumentation is that of the microprocesor. Its inherent flexibility means that it is easy to adapt microprocessor based equipment to specific applications. Thus, full advantage can be taken of components and equipment which have originally been developed with other applications in mind.

4.1 Sensors

As mentioned above development of integrated circuit techniques has led to miniaturisation of equipment and this trend may be expected to continue. The general advantages are obvious but in some cases applications may become feasible which previously were not. For example it is now possible to make identification devices which are small enough to be implanted in animals by injection. Similar devices are beginning to be used also for monitoring body temperature and other health indicators. Modern techniques such as thin film circuitry are being developed for in situ measurement of plant water potential (McBurney, 1988).

Modern technology, besides leading to smaller sensors, is also leading to different types of sensor, such as the optical and fibre optic sensors and the molecular sensors which include ion selective electrodes and biosensors. As yet optical sensors are not widely used apart from laboratory type instruments for constituent analysis which measure near infra-red reflectance. The use of light emitting diodes has enabled this principle to be applied in a compact moisture meter (Stafford *et al*, 1988) and extension to other constituents of agricultural materials such as protein and soluble carbohydrate is being pursued. Fibre optic sensors appear to have a good deal of promise but as yet specific applications are slow to emerge; a particularly interesting possibility is a spatially distributed sensor which can detect changes in, say, gas concentration at any point along its length.

carcasses. By measuring the speed of ultrasound through specific points in the hindquarter of the animal, the fat/lean ratio of the whole carcase can be deduced (Miles *et al*, 1984). Clearly the black box sensor principle has wide applications wherever inaccessibility, cost or convenience mitigate against direct measurement.

Perhaps the most exciting combination of sensors and microprocessors is in machine vision systems, which essentially emulate the human eye and brain. There are many potential applications, especially in inspection, grading and sorting of fruit and vegetables (Marchant, 1988a) and in the control of robots for micropropagation (Onyango, 1988), selective harvesting (Marchant 1988b, c), produce preparation and packing, and possibly for automatic milking. Self-learning features of such systems make them especially powerful.

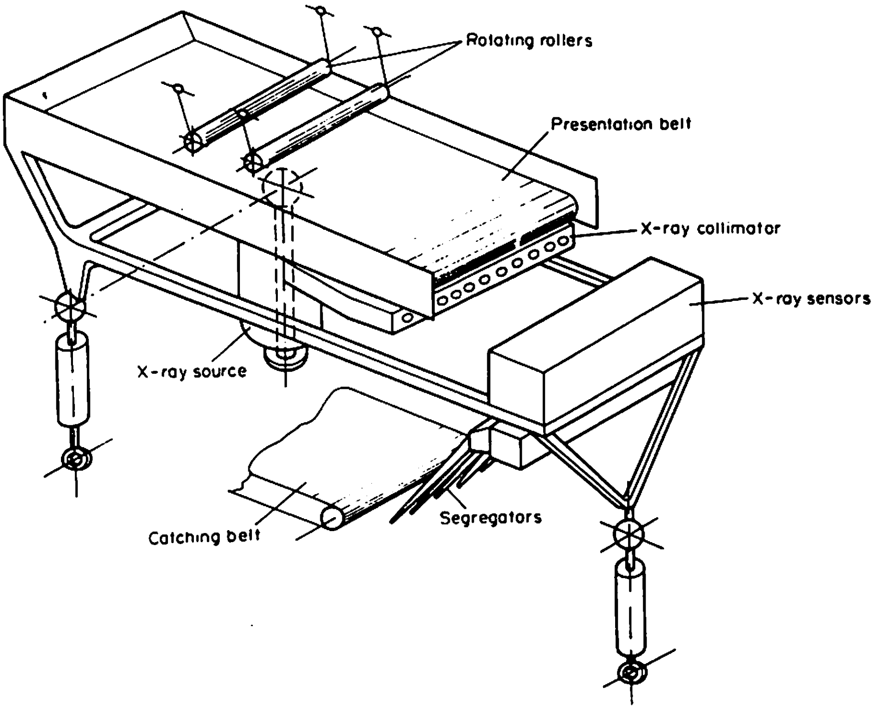
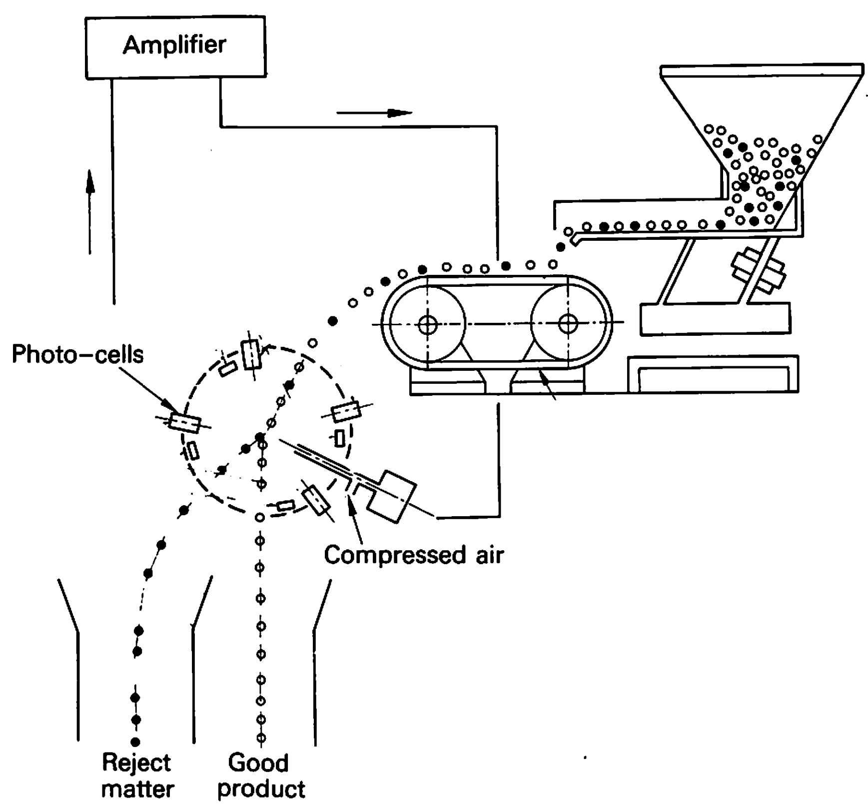


Fig 15 (a) Quality grading X-ray separator of potatoes from stones and clods (SIA)

Certain types of molecular sensors, such as ion-selective electrodes have already found application in horticulture for nutrient monitoring, although the life of such devices is still short. Development of biosensors is proceeding very rapidly, aimed primarily at medical applications and also control of fermentation processes. Clearly, there will be a spin-off in veterinary applications for the farmer. A particularly important opportunity lies in better detection of oestrus in dairy cattle for which a biosensor, probably sensing the luteinising hormone, could be used (Lake, 1987).

Sensors used in conjunction with microprocessors are leading to very exciting possibilities. At the simplest end, the microprocessor can be used to correct for non-linearity, apply temperature corrections etc or stored calibrations. The "intelligent" sensor in which the sensor and microprocessor are on a single chip is already possible. In a rather more sophisticated form, the microprocessor can be used to accept only measurements which are properly made. Thus, in applications to a walk-through weigher, measurements are accepted only when one animal is on the platform. At an even greater level of sophistication is the so called "black box" sensor. In this type of sensor the parameter which is to be measured cannot be easily measured directly but its value can be inferred from some other measurement by using a model stored in the microprocessor. A simple example is the user of ultrasound for *in vivo* assessment of

Fig 15 (b) High speed seed sorter (Gunsons-Sortex Ltd)



4.2 Displays

Twenty years ago any display other than a simple dial or perhaps a pen-recorder would have been hard to find. Now, a very wide range of displays including cathode ray tubes, light emitting diodes, liquid crystal displays and plasma tubes have become common. Digital displays are widely used, and the trend towards graphical displays will doubtless become more marked. Aircraft style head-up displays will shortly appear on cars and perhaps application to tractors and other field machines will follow, especially as operating speeds increase further.

At present there is little demand for these dimensional displays. However, as the amounts of information sensed increase, so will the demand. For example, the technology for accurate position fixing within the field is emerging which will lead to the need for displays of yield, nutrient requirement etc as a function of position.

4.3 Control systems

Until fairly recently many agricultural control systems were simply sequence controllers or simple on-off controllers although proportional and proportional/integral controllers have become common, for environment control in greenhouses.

Current developments are now leading to powerful new classes of control system based on modern control theory. These use simple computer models of the target system and simple measurements to achieve precise control, even during rapidly changing conditions and during start-up and shut down. A typical type of application is the control of high temperature grain driers (Marchant, 1985) where feed back and feed forward control is being applied. Such systems will certainly become widely used because more precise control leads to operating economy and guards against spoilage.

The control systems referred to above are based on a computer model of the process to be controlled. Although this model need only be a simple one, in some cases it may be difficult or impossible to model the process in mathematical terms. In such cases it may be possible to substitute an expert system for the model. The expert system will provide information on the way in which the process responds to changes based upon the knowledge of experts rather than a definitive mathematical model but nevertheless it will still be possible to gain the advantages of modern control techniques. This type of system may well prove to be important in the control of complex systems, such as greenhouse environments.

4.4 Integrated systems

While the flexibility which use of microprocessors allows is without doubt enormously important, the microprocessor also leads naturally to the development of integrated instrumentation systems, in which a multiplicity of sensors for registering a wide range of different parameters can be connected to common processing and display systems by using modern communication buses. Examples of such systems are beginning to appear especially for monitoring and control on tractor/implement combinations and combine harvesters (Moncaster and Harries, 1983).

Similar concepts are also being applied in the application of Information Technology to farm operation and management. In this case fully integrated and comprehensive data collection systems are combined with processing and display facilities to provide "decision support" for the farm manager (Moncaster, 1988), with the aim of helping him to cope with the complex interactions between different aspects of farm operation and management and hence improve the efficiency of the complete enterprise.

5 References

ADAS (1985). Measuring grain moisture content. Grain drying and storage No. 4. *Booklet 2418*, Ministry of Agriculture, Fisheries and Food, Alnwick, Northumb.

Anon (1980). Opening the door to flowmeters. *Milk Prod.* 27, (6), 16–17.

Bailey B J (1975). Measuring glasshouse heat imputs. *The Grower*, 83, 60–70.

Carlow C A (1983). An instructible rejection system for quality grading of potatoes and other produce. *J agric Engng Res*, 28, 373–383.

Cashmore W H (1985). *A career in agricultural engineering.* The Massey-Ferguson Papers.

Cox S W R (1964). Noise measurement and analysis. *The Agric Engr*, 20, 36–46.

Cox S W R (1984). *Sixty years of agricultural engineering, NIAE 1924–1984.* NIAE, Beds.

Cox S W R (1988). *Farm Electronics.* Blackwell Scientific Publications, Edinburgh.

Filby D E (1967). Methods of measuring strain. *Proc Agric Engng Symposium, NCAE, September 1967.* Paper No 2/E/23, IAgrE.

Hamblin H J (1951). Apparatus for the testing of agricultural machinery. *The Engr*, 192, 141.

Hamblin H J, Chalmers G R, Raybould F W (1954). Hydraulic drawbar dynamometers. *Technical Memorandum 44*, NIAE, Beds.

Harries G O, Gale G E (1968). An electronic classifier for simulated apples. *J agric Engng Res*, 13, 374–378.

Hawkins J C, Rogers O J J (1950). A strain gauge dynamometer rig for determination of soil forces on plough bodies. *Br J App Sci*, 1, 247.

Henshall J K, Campbell D J (1983). The calibration of a high resolution gamma-ray transmission system for measuring soil bulk density and an assessment of its field performance. *J Soil Sci*, 34, 453–463.

Hobbs J, Hesse H (1980). Electronic/hydraulic hitch control for agricultural tractors. *SAE Technical Paper Series*, 801018, Society of Automotive Engineers Inc., Warrendale, USA.

Johnson E K, Hines R L, Alsmeyer R H, Campbell E L, Platt W T, Webb J C (1964). Ultrasonic pulse-echo measurement of livestock physical composition. *Trans Am Soc Agric Eng*, 7, 246–249.

Kilgour J (1967). A combined torque and thrust meter. *Proc Agric Engng Symposium, NCAE, September 1967*, Paper No 2/E/24, *IAgrE.*

Lake J R (1987). An assessment of the prospects for improved oestrus detection on the farm. Proc. of 3rd Symposium *"Automation in Dairying"*, Wageningen, 159–165.

Lindahl I L (1966). Detection of pregnancy in sheep by means of ultrasound. *Nature*, 212, 642–643.

McBurney T (1988). A temperature controlled plant psychrometer. *Plants and soils, July.*

Manby T C D (1964). Safety aspects of tractors and their testing. *The Agric Engr*, 20, 53–61.

Marchant J A, Frost A R (1985). Spray boom attitude control. *Proceedings of Agrimation 1 Conference, Chicago, Feb 1985*, ASAE, St Joseph, MI, USA.

Marchant J A (1985). Control of high temperature continuous flow grain driers. *The Agric Engr*, 4, 40, 145–149.

Marchant J A (1988a). System architecture for high speed sorting of potatoes. Conf paper at *"Automated inspection and high speed vision architectures II"*, SPIE, Cambridge, Ma, USA.

Marchant J A (1988b). Robotics in agriculture and food production. Proc. of conf. *"Engineering advances for agriculture and food"*, IAgrE, Cambridge.

Marchant J A (1988c). Computer vision in agricultural engineering. *The Agric Engr,* 43 (2).

Matthews J (1963a). The design of an electrical capacitance-type moisture meter for agricultural use. *J agric Engng Res,* 8, 17–30.

Matthews J (1963b). Automatic moisture content control for grain driers. *ibid,* 8, 207–220.

Matthews J (1964–1966). Ride comfort for tractor operators. Parts I–IV. *J agric Engng Res,* 9, 3–31 and 147–158; 10, 93–108 (with Talamo J D C); 11, 44–57.

Matthews J (1967). The collection of test and experimental data for computing. *Proc Agric Engng Symposium, NCAE.* Paper No. 2/E/22, *IAgrE.*

Miles C A Fursey G A J, York R W R (1984). New equipment for measuring the speed of ultrasound and its application in the estimation of body composition of farm livestock. Lister D. (editor) *In vivo measurement of body composition in meat animals.* Elsevier Applied Science, 93–105.

Moncaster M E, Harries G O (1983). Automatic control of tractors and field machines. Int conf on: *Robotics and intelligent machines in agriculture,* Tampa, USA, ASAE Publication 4–84.

Moncaster M E (1988). Applications of information technology to agriculture. Conference paper No. 88.127, *Ag Eng 88,* Paris.

Moran P (1980). Full-scale experiments to acquire wind loading data for use in the design of agricultural buildings. *J agric Engng Res,* 25, 287–297.

Nickerson D (1946). Color measurement and its application to the grading of agricultural products. *USDA Publication 580.*

Onyango C M (1988). Use of an adaptive pattern classifier for agricultural objects. Conf. paper No. 88.125, *Ag Eng 88,* Paris.

O'Sullivan M F, Dickson J W, Henshall J K, Anderson G (1983). Electronic collection and storage of data from a hand-held recording soil penetrometer. *J agric Engng Res,* 28, 175–178.

Owen V M (1967). Control of temperature and humidity by ventilation and heating: for animal production. *Proc Agric Engng Symposium, NCAE.* Paper No 1/E/9, IAgrE.

Palmer J, Kitchenman A W, Moore A B, Owen G M (1973). Adaptation of a commercial potato harvester to a commercial X-ray separator. *J agric Engng Res,* 18, 355–367.

Raybould F W, Nation H J (1950). A hydraulic power take-off dynamometer. *Technical Memorandum 44,* NIAE, Beds.

Sanger T R (1985). Measurement and control of temperature, humidity and carbon dioxide concentrations in greenhouses. *Proc International Symposium on Farm electronics and computing,* RASE Stoneleigh, 269–287.

Sharples R, Jameson J (1984) Computerised atmosphere control in apple stores. *Fruit, Veg & Science,* AFRC. London.

Simons A K (1964). Better tractor ride improves driver safety, health and productivity. *The Agric Engr, 20, 47–52.*

Smith R A, Turner M J B (1975). Electronic aids for use in fatstock weighing. *J agric Engng Res,* 19, 299–311.

Sokol D G (1983). Next generation radar sensor for true ground speed measurements. *Proc Agricultural Electronics - 1983 and beyond,* Chicago, 76–84, ASAE, St. Joseph, MI, USA.

Stafford J V, Weaving G S, Bull C R (1988). Portable solid state moisture meter for grass and forage. Conference paper No 88.128, *Ag Eng 88,* Paris.

Street, M J (1979). A pulse-code modulation system for automatic animal identification. *J agric Engng Res,* 24, 249–258.

The Brit Soc Res Agric Eng (1948). Marconi moisture meter, type TF 933. *Test Report RT7,* NIAE, Beds.

The Brit Soc Res Agric Eng (1952). *NIAE and SMTS report for the period 1 October 1949 to 30 September 1951.* BSRAE, Beds.

The Electricity Council, Farm Electric Centre (1986). The control of ventilation in livestock housing. *Technical Information AGR 7-4.* Farm Electric Centre, NAC, Stoneleigh.

Thiel C C, Dodd F H (Eds) (1977). *Machine Milking.* National Institute for Research in Dairying, Shinfield.

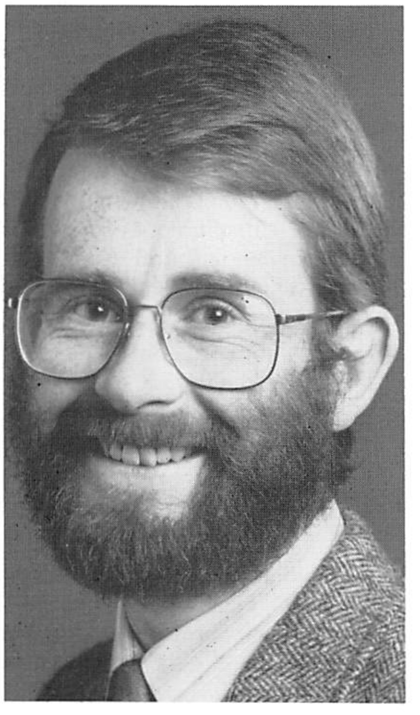
Turner M J B, Gurney P, Crowther J S W, Sharp J R (1984). An automatic weighing system for poultry. *J agric Engng Res* 29, 17–24.

Winsor G W, Hurd R G, Price D (1979). Nutrient Film Technique. *Grower's Bulletin 5,* Glasshouse Crops Research Institute, Littlehampton, Sussex.

Winspear K W, Morris L G (1959). Temperature integrating bottles for measuring mean air temperature. *J agric Engng Res,* 4, 214–221.

Moisture sensing and control in a recirculating-batch grain dryer

D M Bruce



Summary

SIMULATION of a recirculating-batch grain dryer showed that non-uniform drying occurs because of the necessary presence of an unventilated zone of grain. The moisture non-uniformity was shown to recur cyclically with a period of one recirculation time. At low grain recirculation rates the moisture content (mc) non-uniformity can make it difficult to assess the completion of drying and hence affect the marketability of the grain. To overcome this an algorithm is proposed which, by altering recirculation rate, ensures that there is no moisture gradient when the desired final moisture content is reached. A single sensor in the grain cannot measure a representative mc because of the non-uniform drying, but the mean value of two mc sensors at particular locations was shown to be very close to the true mean mc.

1 Introduction

In the UK, drying of grain with heated air, necessary to reduce it to a moisture content suitable for storage, is normally done in through-circulation packed-bed dryers, either on farms or at centralised plant. Large dryers usually operate in continuous-flow, whereas smaller machines dry batches. In some of these batch dryers the grain is recirculated several times as it dries to give a more uniform treatment to the grains. When the mc of the batch is below a target value the air heater, usually gas or diesel fired, is turned off and the batch is cooled while recirculating.

Deciding when to stop drying is important because overdrying by one half percent mc can cost at typical prices 55p/tonne in lost weight for sale and 15p/tonne in additional fuel cost. Underdrying is more serious and can result in spoilage in store or rejection by purchasers so, for safety, operators of dryers tend to regulate the mc to a value below target. For this reason overdrying is common, and a significant saving could be made by better mc control. This paper investigates the problem of automatic moisture control in recirculating batch-dryers, proposes a novel method of sensing and an algorithm for control.

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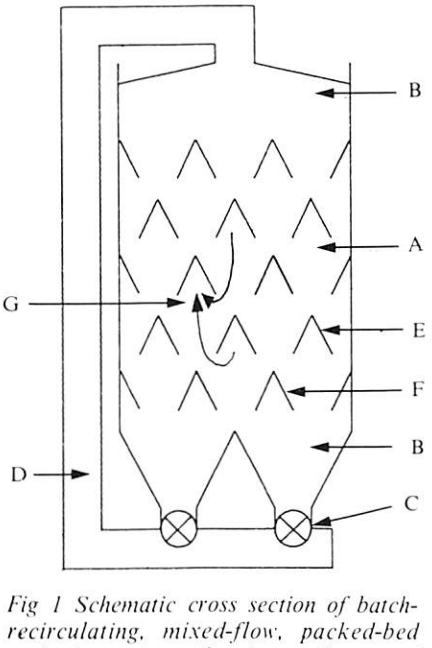


Fig 1 Schematic cross section of batch-recirculating, mixed-flow, packed-bed grain dryer. A ventilated zone, B parts of unventilated zone, C discharge device, D recirculation device, E inlet air duct, F exhaust air duct, G air paths within grain bed

2 Recirculating-batch dryers

2.1 Description

A recirculating-batch dryer, (figure 1) consists of a zone where the grain is ventilated and regions above and below this where there is little or no ventilation. The ventilated zone is most commonly in cross-flow where grain is confined between perforated metal sheets or mixed-flow where inverted 'V' shaped sheet metal ducts penetrate the packed bed to allow air flow through the grain in a mix of co-current, counter-current and cross flow. Because the volume of a batch of grains reduces by approximately eight percent during drying for a typical mc range of 0.25 to 0.175 kg/kg measured on a dry weight basis, a batch dryer must include a reserve volume of grain so that shrinkage during drying does not expose the top air path.

2.2 Model

To investigate the behaviour of mixed-flow recirculating-batch dryers, an existing computer simulation of continuous flow-drying (Bruce, 1984) was modified to include recirculation and a delay period to represent the unventilated zone. The model consisted of four differential equations given by Nellist (1987) and constitutive relationships for drying rate constant (O'Callaghan *et al*, 1971) equilibrium mc (Nellist, 1987) and heat transfer coefficient (Sokhansanj and Bruce, 1987). Further details of the mixed-flow simulation in its continuous-flow form are given by Bruce (1984).

For simplicity it was assumed that the grain neither cooled nor dried between leaving the bottom of the ventilated zone and re-entering it at the top and that no back mixing or shrinkage occurred in the dryer. Redistribution of moisture within grains in the unventilated zone was also excluded from the model because of the simple, logarithmic equation used to describe the drying rate of exposed grains, Eq (1).

$$\frac{dx}{dt} = -bx \qquad (1)$$

where the value of b, units s^{-1}, is correlated with drying air temperature with the Arrhenius relationship from O'Callaghan *et al* (1971) for wheat, Eq (2).

$$b = 2000 \exp(-5094/T_a) \qquad (2)$$

For this work a drier with 11 beds alternately co-current and counter flow was chosen. The effective bed depth (depth of a bed with parallel top and bottom faces containing a grain volume equal to that between an inlet and an exhaust row of air ducts) was 0.18m, the ventilated zone was 60% of the total grain mass, air mass flow rate was 0.2 kg $s^{-1}m^{-2}$ grain mass flow rate was varied in the range 1000 to 10000 kg $h^{-1}m^{-2}$, heated and ambient air temperatures were 90°C and 15°C respectively, inlet and target mcs were 0.25 and 0.177 d.b. respectively. All these values except the variable grain flow rate were typical of existing driers of the mixed-flow type.

3 Results of simulation

3.1 Effect of grain recirculation rate

The model was run for a range of grain recirculation rates. There was no significant effect of the recirculation rate on the batch drying time, table 1, but within a batch the recirculation rate determined the non-uniformity of drying.

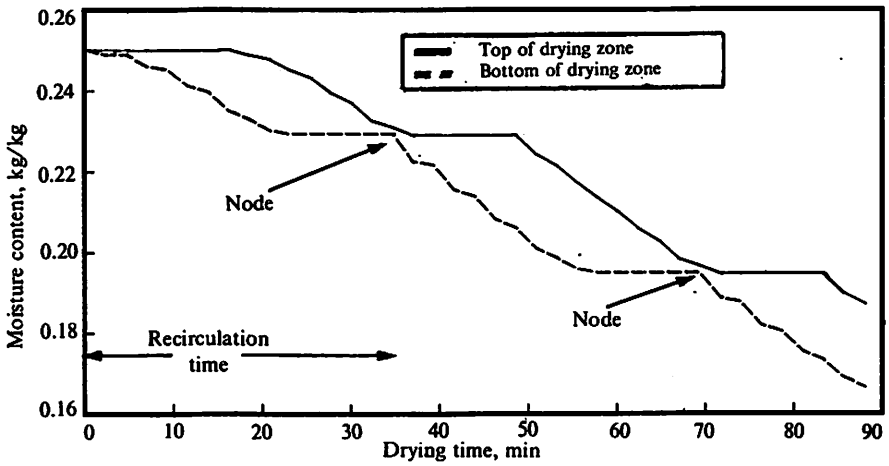


Fig 2 Maximum (top of drying zone) and minimum (bottom of drying zone) mc versus drying time, showing how mc spread varies during each recirculation time

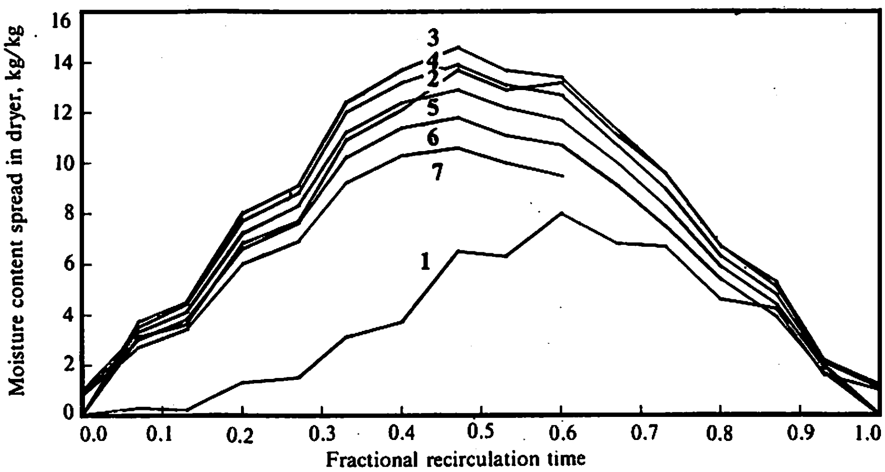


Fig 3 Variation in mc spread with successive recirculations during drying. Recirculations are numbered from the start of drying

Table 1 Effect of recirculation rate on batch drying time

Recirculation rate, kg h^{-1} m^{-2}	Drying time, min
1000	88.2
1500	89.1
3000	89.5
5000	89.5
7000	89.5
10000	89.7

3.2 Non-uniform drying

Output from the model showed that the presence of the unventilated zone gave rise to a spread of mc within a batch because at moderate recirculation rates the grain passing through the ventilated zone dried significantly while that in the unventilated zone remained at its initial mc. As drying proceeded the spread of mc within the batch increased to a maximum and then reduced again to zero after one complete recirculation, figure 2. The same cycle was reproduced in each subsequent recirculation though after the batch had been heated, the spread of mc reduced as drying proceeded, figure 3, because of the logarithmic approach to equilibrium mc characteristic of grains. At low recirculation rates, ie long recirculation times, the maximum spread in mc during drying became larger in direct proportion to the recirculation time, figure 4. This observation highlighted two problems — moisture spread at end of drying and moisture sensing.

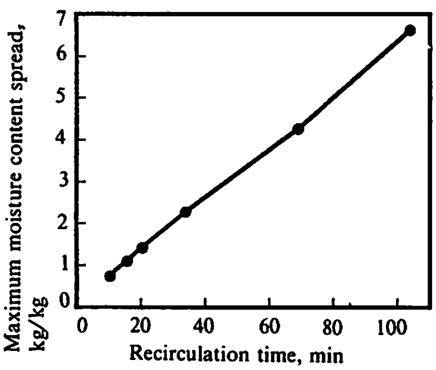


Fig 4 Effect of recirculation time on maximum spread in mc during the whole drying process

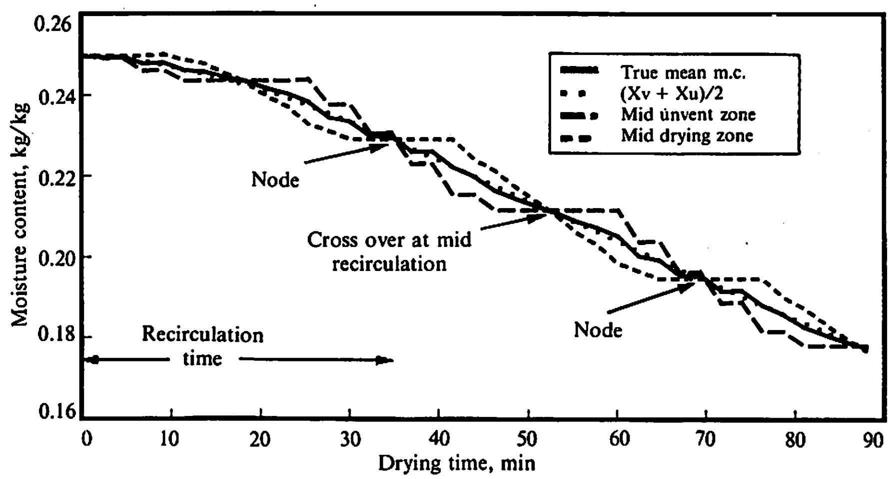


Fig 5 X_v, X_u, the mean of X_v and X_u and the true batch mc versus drying time. X_v and X_u cross over every half recirculation time

3.3 Moisture spread at end of drying

The simulation showed that when the batch had reached the target mc the spread of mc was determined by the point at which drying was stopped in the cycle. If the end of drying happened to coincide with a point of zero moisture spread, referred to hereafter as a node, then the batch mc was uniform, but if the end of drying fell near the mid-point between nodes the range in mc could be significant. One way to avoid this was to use a high rate of recirculation to reduce the maximum spread of mc but this requires more expensive grain moving equipment and causes greater physical damage to the grain. An alternative would be to adjust the recirculation rate so that the drying process was always completed at a node. This could be done by an automatic controller linked to sensors to determine the progress of drying and using an algorithm presented in Section 4.

3.4 Moisture sensing

The second problem is sensing the grain mc both to detect a node and to determing the overall batch mc. In continuous-flow dryers the mc at output may be measured directly by a suitable sensor, or inferred from an exhaust air temperature probe at the end of the drying zone. However, in a recirculating batch dryer there is no one location where the mc is, at all times, representative of that of the batch as a whole. Figure 2 shows the mcs at locations in the dryer and reflects what the ideal sensor would show. Detection of a node is easier. To detect the nodes predicted by the simulation model, two sensors could be located at different points in the dryer, so that their readings will coincide at a node. However, by positioning these two sensors at two particular points the mean batch mc can also be inferred.

Figure 5 shows the predicted mc at the mid-points of the ventilated and unventilated zones. The mc values coincide every half recirculation time but it is significant that the mean of the two values is close at all times, not just at the nodes, to the true batch mean mc. Thus two sensors positioned one at the mid-point of each zone can make possible both node detection and measurement of overall mc.

4 Control algorithm

In order to alter automatically the recirculation rate so that drying is completed on a node, an algorithm suitable for implementation on a microprocessor is required. Such an algorithm is shown in figure 6.

To calculate td, the drying time to target mc, a function is required of the form

$t_d=f(X_o,X_t,T_a,T_{gf}$, grain type, dryer design) (3)

Data to enable the form and coefficients of the function f to be determined for a particular model of dryer and grain type can be calculated using the simulation model with appropriate parameters. In a similar way, the moisture loss during cooling may be computed and expressed as a suitable function.

Estimation of t_d once one or more nodes has been reached would require an optimisation process taking into account all the moistures measured to that point, perhaps weighted in favour of the more recent values. This would require a large number of numerical operations but the drying process may typically take 1-3h, so the required processing speed is likely to be within a microprocessor's range.

The effects of grain layers mixing during drying may make the detection of node points more difficult and this together with grain shrinkage, should be investigated further to develop a practical control algorithm. The method of sensing batch mc with two sensors and of controlling the recirculation rate are the subject of a patent application (Bruce and Nellist, 1987).

5 Conclusions

Results from simulation work suggest that the mean mc of the batch can be calculated from only two sensors and that this mean can be used to alter the recirculation rate of grain so that the final mc of the grain is uniform. The algorithm proposed for this control of recirculation rate requires data from simulation of particular dryers under a range of conditions. A suitable simulation program exists.

Nomenclature

- b drying coefficient in Eqs (1) and (2) s^{-1}
- n number of recirculations to end of drying
- T_a drying air temperature °C
- T_{gf} drying air temperature at end of drying °C
- X_b batch mc kg/kg
- X_o initial batch mc kg/kg
- X_r target batch mc kg/kg
- X_i modified target mc allowing for moisture loss during cooling kg/kg
- X_t mc from sensor in unventilated zone kg/kg
- X_v mc from sensor in ventilated zone kg/kg

References

Bruce D M (1984). Simulation of multiple-bed concurrent-, counter-, and mixed-flow grain driers. *J agric Engng Res, 30, 361–372.*

Bruce D M, Nellist M E (1987). Patent application 8719470, UK Patent Office, London.

Nellist M E (1987). Modelling the performance of a cross-flow grain drier. *J agric Engng Res, 37, 43–57.*

O'Callaghan J R, Menzies D J, Bailey P H (1971). Digital simulation of agricultural drier performance. *J agric Engng Res, 16, 223–244.*

Sokhansanj S, Bruce D M (1987). A conduction model to predict grain temperature in grain drying simulation. *Trans Am Soc Agric Engrs, 30, 1181–1184.*

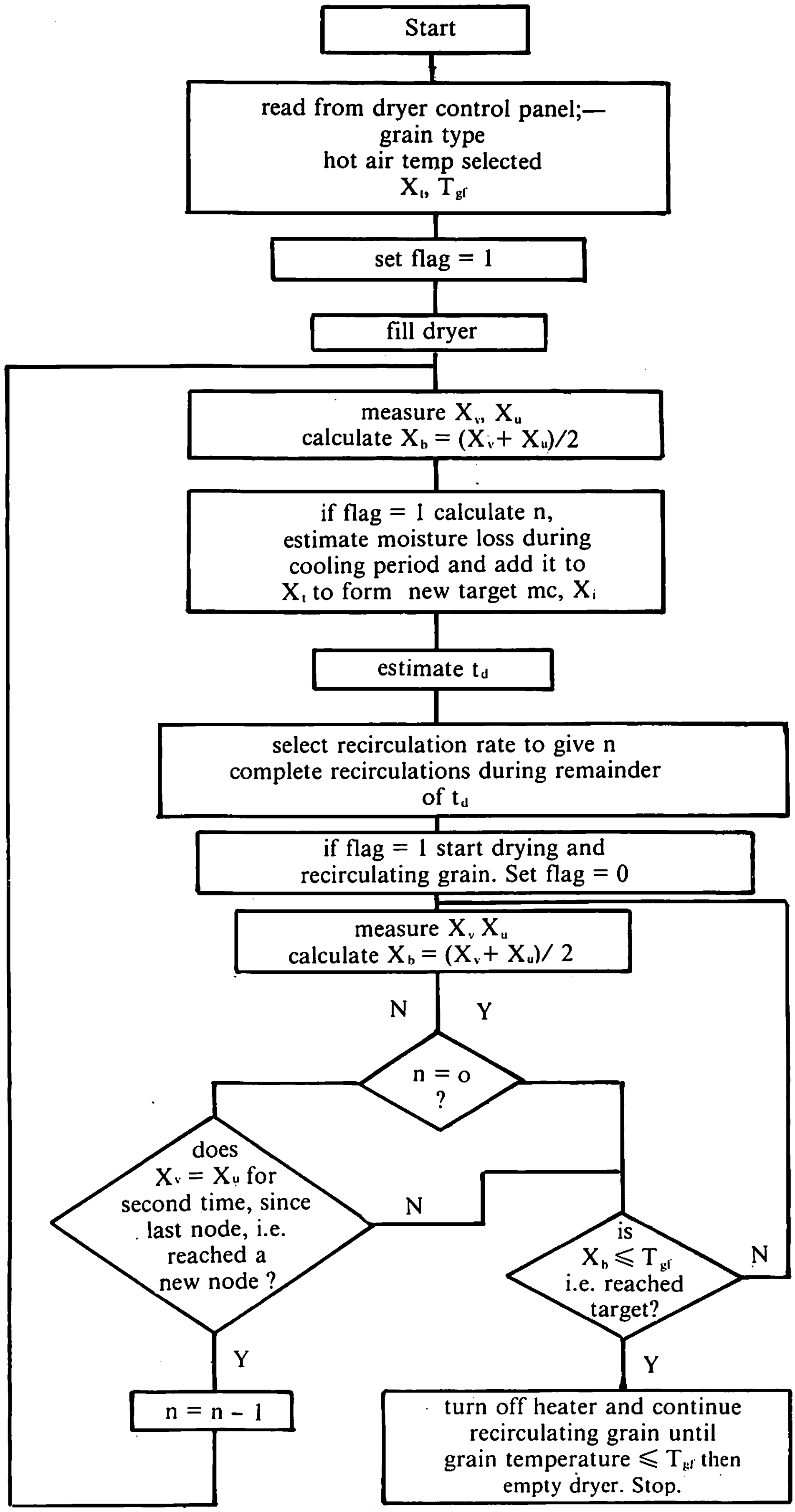


Fig 6 Flowchart of proposed algorithm to control recirculating-batch dryer

The Agricultural Engineer

AgEng Items

Book Reviews

M J Hann

Food Research Institute Studies, Vol XXI, No 1, 1988
Publisher: Stamford University, Stamford, California 94305

THE journal contains 3 papers which are:

(i) *Java's Critical Uplands — Is Sustainable Development Possible?* Frederick C Roche, Senior Research Associate, Division of Nutritional Sciences, Cornell University.

The paper develops the evolution of the upland agriculture of the island of Java, Indonesia. The thrust of the work is to suggest that the principal problems will be improved provided the production of upland commodities is linked to reduced soil erosion. To facilitate this evaluation, efforts must be made in development which provide secure markets and prices for staples. This can be achieved by changing relative prices for more specialised crops suited to the region.

It is a well researched work, if somewhat laboured, which sets out to answer the question posed in the title. As one would expect, it can only suggest a partial solution so any resolution is still frustratingly far from being provided. A very specialised paper for those with an interest in developing agro-economic systems.

(ii) *Research and Development of a Biological Innovation: Commercial Hybrid Wheat.* M K Knudson and V W Ruttern, Department of Agriculture and Applied Economics, University of Minnesota, Twin Cities.

This paper analyses the history of commercial development of hybrid wheat paying attention to the relationships between science and technology in bringing to commercial use a hybrid wheat. It also pays attention to the interaction of public and private researchers in the process. A very specific area of reading, but none the less providing an insight into the process of research through to product.

(iii) *Animal-Drawn Implements For Small Farms in Mexico.* B G Sims (AFRC Engineering, Silsoe), B F Johnson, A L Ormstead, (University of Davis, California) and S J Maldonado, (Agricultural Engineering Project, Vera Cruz). This paper describes the programme of the Mexican National Agricultural Research Institute (INIA) which sets out to encourage local manufacturers of promising new implements.

The aim is to introduce implements which are economically viable to small farmers. It concentrates on recent improvements in the design of multipurpose animal drawn tool bars, the Yanticulator developed for the International Crops Research Institute of the Semi Tropics (ICRISAT) by AFRC Engineering and the Multibarra developed by INIA Engineers from British and French designs. It considers the political, financial and manufacturing problems of introducing these new machines against the existing infrastructure of Mexican agriculture, the paper concludes that the introduction of improved animal drawn equipment is an attractive possibility in Mexican agriculture, probably replacing the hire of tractors for some tasks. This approach is backed up by a rigorous financial appraisal.

The paper is clearly written and contains a considerable amount of background and data on the mechanisation of Mexican Agriculture. The case is well argued and forms a good reference to further work in the area for anyone wishing to become informed on this aspect of mechanisation in a developing economy.

Michael Hann is a Lecturer at Silsoe College and recently joined the Editorial Panel of the Journal. He has taken on the task of Book Reviews.

Principles of Farm Irrigation System Design
Larry G James *1988*
Publisher: John Wiley and Sons, Ltd., Chichester, W. Sussex
543 pages.

THE book is targeted at "beginners" in irrigation. The author suggests that it has been designed to guide the reader from a basic knowledge of soils, botany and hydraulics through to "state of the art" irrigation system design and management. In this respect I feel that the author has sucdeeded in meeting his objective. However it must be pointed out that it is in no way a design manual but more a teaching/learning tool. Further, it is an American text book using American examples and methods almost exclusively, which has obvious disadvantages. The units used are rather mixed between imperial and SI which may cause some confusion. Some effort has been made to reduce this by the use of unit constants in equations and introducing only one unit system in any particular problem.

The style of writing and presentation is very good, easy to follow and there are over 60 solved problems and 190 'homework problems' (unfortunately a solution manual is not included) and 100 references to aid the students studying progress. One particularly good feature is that every chapter starts with an introduction which includes learning objectives and an overview of the material covered. The contents are:— Chapter 1: Irrigation requirements and scheduling — an overview of soil/plant/water relationships leading to methods of quantifying irrigation requirements and schedules. Chapter 2: Irrigation systems and system design fundamentals — the types and function of irrigation systems and major design steps. It also presents methods of determining irrigation requirement effectiveness and cost. Chapters 3 and 4: Deal with water for irrigation in a rather simplified manner and pump operation, performance and selection in a much more satisfactory approach. Chapters 5, 6 and 7: Deal with the operational characteristics, management and design of sprinkler, trickle and surface irrigation systems. This difficult area is dealt with clearly but suffers from having a very American based approach. Also some areas, such as trickle design, are rather poorly treated. The final chapter deals excellently with the principles and methods of measuring flow both in channels and pipelines.

In general this is a very good textbook for students reading the subject of Irrigation Design for the first time. Unfortunately it is rather expensive but will be an excellent addition to college and university library shelves.

Farm Electronics
S W R Cox
Publisher: Blackwell Scientific Publishers Ltd., Edinburgh.
ISBN: 0-632-01832-1
300 pages. RRP £14.95

SIDNEY COX'S latest contribution to the unravelling of electronics in agriculture has come as a welcome relief to those who have been trying to keep up with the latest developments. Not only has electronics become very complicated in recent years but the proliferation of new gadgets over the farm has become bewildering to say the least.

He treats the subject with a rare authority but has managed to combine a recent review with a deeper explanation of the principles of design. This approach will be useful to those who wish to know more than just "what the box looks like".

The book starts with a good introduction to the fundamentals of instrumentation and control to giving the reader a primer from which to work. Further chapters cover a number of specialist areas, ie livestock environment, livestock management, field machines, materials handling, crop environment and quality monitoring. These cover a number of alternative proprietary products and the way they operate, including in some cases, their advantages and constraints. The final chapter, future developments gives a most interesting glimpse of what is yet to come. Each chapter includes a further reading list for those who would like to delve into the subject in more depth.

There are two appendices of useful information. The first covers the usual SI units and also gives references for some calibration services and standards. The second appendix is particularly useful as it is a glossary of terms that have appeared throughout the book.

In general, we found the book to be a mine of information, not only with regard to what products are currently available but also on how they work. The book is well presented and easy to read with a good proportion of photos and diagrams.

NB. Simon Blackmore also assisted with this review.

United Kingdom Register of Research on Irrigation, Drainage and Flood Control, 1988
Publisher: Overseas Development Unit of Hydraulics Research, Wallingford
99 pages.

THIS 2nd edition of the Register has been compiled with the backing of the British National Committee of the International Commission on Irrigation and Drainage. It follows two years after the first edition which allows the average research project to appear in at least one register, a practice which is expected to continue in subsequent editions.

The aim has been to compile a register of all current research in irrigation, drainage and flood control. This has been achieved by sending out questionnaires to a wide range of researchers. This has increased the number of entries to over 200, of which around 50 are new to the list. It is claimed that most of those which also appeared in the first edition have been updated. The Research Entries are under the following titles and subtitles:

1. Irrigation (Hydrology, Agriculture, Engineering Management).
2. Drainage and Flood Control (Agriculture Engineering Management).
3. General (Monitoring and Evaluation, Sociology and Economics, Health, Environmental, Legal)

Each project is numbered (1 to 218) and is in the following format: Title, Co-workers, Liaison address, Sponsors, Project details, Abstract, Publications and Keywords.

This layout provides an easy to follow, clear register for reference. The keywords are particularly useful as a guide to the work area and are used to index projects by subject. There are in fact four Indices by (a) Researcher, (b) Institution, (c) Subject and (d) Location. These I found easy to follow with little or no confusion.

Finally there are the Institutional entries. This gives details of the ten most prominent Research Establishments in the area, including background, current research areas and a reference system to the projects held in this register. This publication is well planned and well presented. The reviewer found it an easy to use and extremely informative register of the current research in Britain.

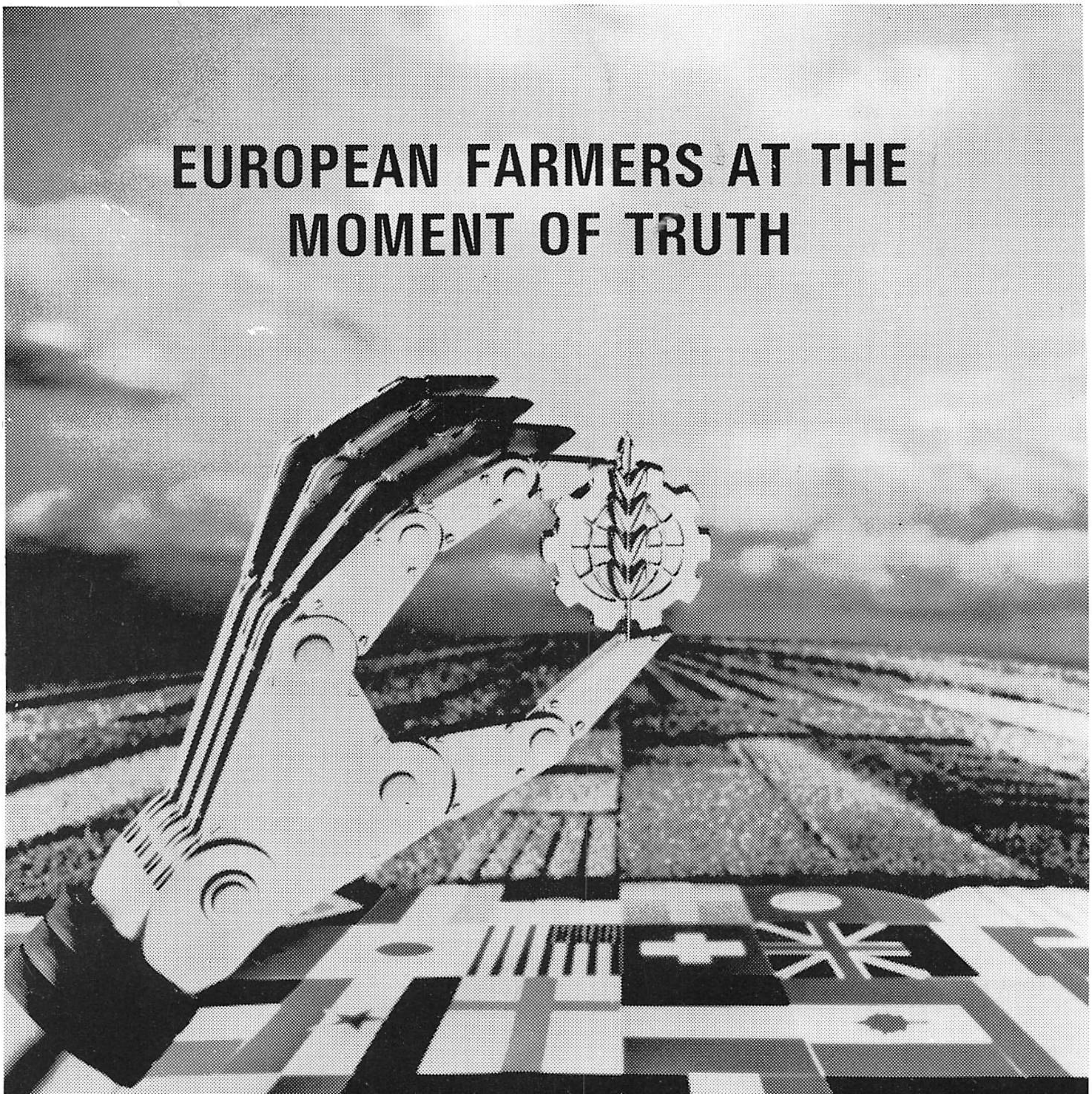
Farm Implement and Machinery (Multilingual Illustrated Dictionary)
Publisher:
ISBN: 2-92433-39-4.
520 pages, RRP: £17.25

THE aim of this book is to provide a multilingual (German, English, French, Spanish, Italian and Dutch) illustrated dictionary to aid people in choosing the appropriate term in another language for a certain machine or hand tool.

The range of the machines included is very comprehensive. They are divided into groups which will be recognisable, eg sowing, planting, irrigation, etc and these are displayed in the table of contents.

Each page has pictures of types of machine with its name and certain key features in the six languages. There is also an index for each language to aid the user.

The book is pocket sized and fairly comprehensive. However, the quality of reproduction and binding is very poor. Further, the layout is not easy to follow with illustrations of poor quality and the key words in a very jumbled arrangement. The reviewer found the dictionary difficult to use and overpriced.


EUROPEAN FARMERS AT THE
MOMENT OF TRUTH