THE AGRICULTURAL ENGINEER

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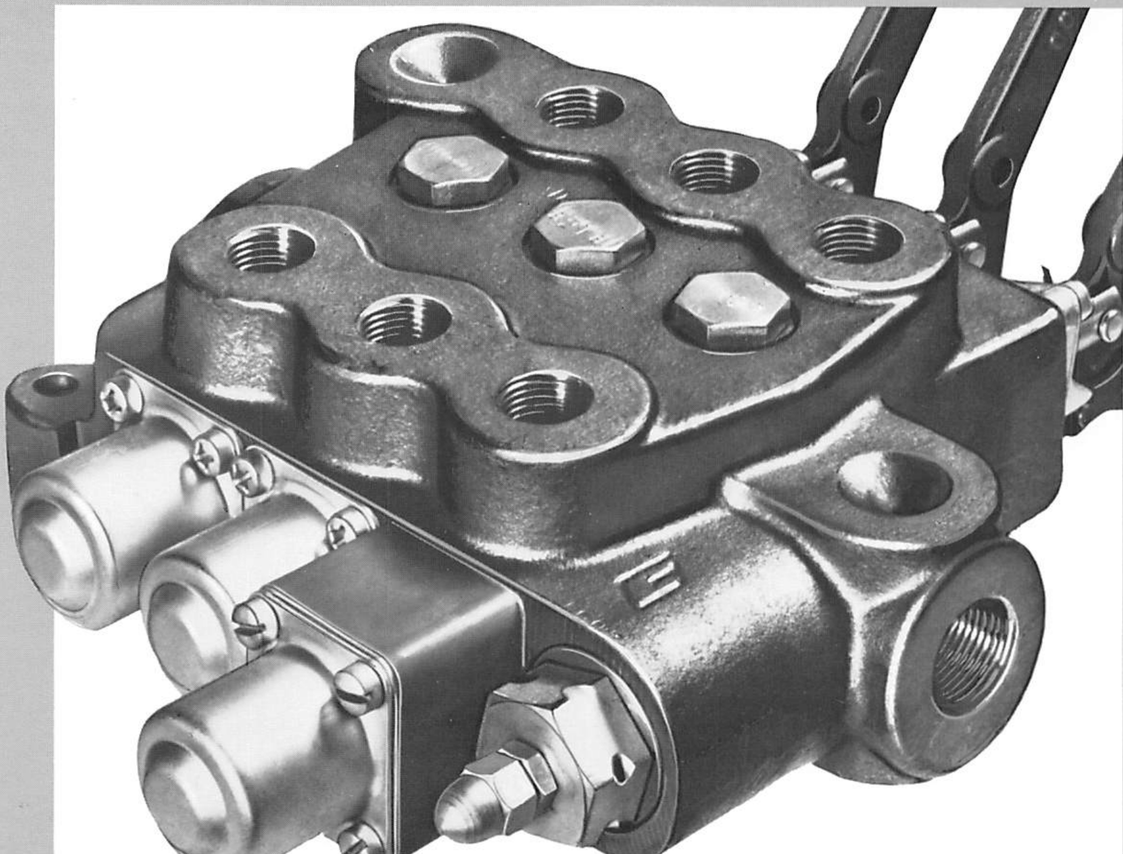
3 NEW WAYS TO ADD COST CONTROL TO HYDRAULIC CONTROL.



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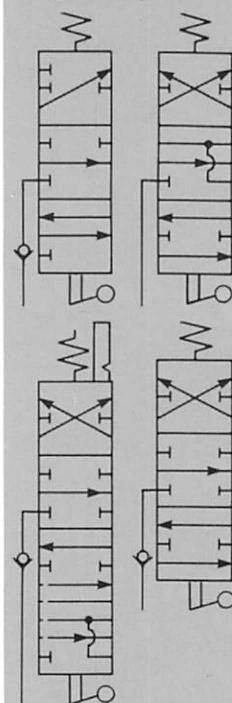

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Cover – Mechanical harvesting of top fruit. *See pages 48 – 50.*

Engineering in horticulture

Ivan B Warboys

THE south east of England with its fertile soils and Continental climate has a high proportion of horticultural crops. The choice of "Engineering in Horticulture" as a topic for the Spring conference of the Institution was therefore a most appropriate one for sponsorship by the London/Kent Branch. Wye College, the venue for the conference, has always had a strong interest in teaching and research in horticulture. Adjacent to the Centre for European Agricultural Studies, (CEAS), in which the Conference was held is the complex of buildings which originally housed the Swanley Horticultural College for women. In 1945, it was amalgamated with the South East of England Agricultural College to become Wye College, a School of the University of London.

Horticulture is basically an applied plant science and deals with crops as diverse as vegetables on a field scale, fruit, hops, glasshouse crops, shrubs and flowers. The difficulty was therefore to select subjects for the conference which could be covered in one day, and which would be of particular interest at this point in time to agricultural engineers.

Although horticultural crops can be found on a variety of farm sizes and enterprises, the specialist grower whether as an apple producer, or growing glasshouse tomatoes has been particularly hard hit by the high rise in the costs of primary energy in the form of heating oil, and electricity, as well as for fertilisers and crop protection chemicals. Hence for this conference it was thought appropriate to consider energy use and conservation, for example for the glasshouse industry, and for fruit storage.

In a recent paper to the *Journal of Agricultural, Engineering Research, 1980 (25).* Stanhill showed that tomatoes, the most important food crop grown under glass, require nearly 40 times more gross energy (approximately 30,000 G J/ha) when grown in a heated glasshouse in southern England, than in a similar but unheated glasshouse in Israel. This extra input of energy is just about offset by the energy cost of air freighting tomatoes from the Mediterranean to northern Europe. Nevertheless, one wonders how much longer we can afford in energy terms to produce a crop which, on the basis of metabolisable energy produced per unit of non-solar energy input, has an efficiency of less than 1%! Apparently there are still consumers who are prepared to pay £1 per lb for tomatoes and whilst this market for early tomato production expands there will continue to be a tomato industry in the UK. However, the challenge to the engineer is to reduce these energy inputs by more efficient systems.

A further energy aspect requiring attention is the more efficient use, and application of crop protection chemicals. Crop protection chemicals are a major cost item to the fruit grower and yet without them the modern grower would be unable to produce a clean marketable product which can compete in the rest of Europe. The need for frequent applications of materials throughout the winter and growing season means that the spraying machine is the single most important piece of equipment used by the horticulturist. New systems and machines require new skills to minimise waste of chemicals, and match power requirements to those available from the size of tractor found on horticultural holdings. Further innovations are in the research and development pipeline which are likely to give opportunity for manufacture and marketing of original equipment on a world wide scale.

By contrast with the glasshouse industry where because of massive changes in the costs of fuel, labour costs account for less than one percent production costs, labour costs for harvesting fruit crops are high. Additionally despite current unemployment, a supply of suitable

labour for harvesting easily damaged fruit crops has become more problematical. Over the last decade there has been a sharp decline — by some 50% — in the number of permanent staff employed in the horticultural industry. Such experienced staff are hard to replace. Although, there would appear to be sufficient casual labour seeking part-time employment, social changes have seen a different type of person coming forward, generally less experienced, requiring training, transport, probably demanding childminding facilities and a shorter working day. Hence despite the apparent surplus of casual labour at picking time, and the development of pick-your-own systems, mechanised harvesting is still required both for hard fruits, destined for long term storage, and for soft fruits required by the processor.

Finally, we must not forget that Wye College is the main centre for Hop Research in the UK and, despite the biochemist, the demand for natural hops remains unabated. In this crop innovations by growers are, because of the small size of the industry, commonplace in England. However, hops are grown world wide in Europe and North America and the opportunity for specialist manufacture of hop machinery should not be ignored.

Changes for the Journal

THE Spring 1981 issue of the Journal was the last one produced under the Editorship of Brian Stenning. Writing his last Editorial, Brian outlined the changes in the activities of the Institution since be assumed office five years previously. What he omitted to mention was his own tremendous contribution to the Institution through his Editorship.

Five years means 20 Journals with their need for copy and its processing into an acceptable mix suitable for the very diffuse membership which goes to make up the Institution. Freed from the domestic minutiae which has become the province of the widely acclaimed Newsletter, Brian Stenning has given us a Journal which reflects admirably the proceedings of the Institution as well as covering development over the extremely diverse subjects which are Agricultural Engineering.

The Editorial Panel (for its current composition see page 29) is continually looking for improvements in the Journal both in its readability and its scope. In particular the Panel is concerned that the learned society aspect of our activities should have a suitable forum for publication.

Consequently it is intended that in future, papers which have been refereed by a scientific authority acceptable to the Editorial Panel shall be so labelled in the Journal. This will not imply that non-refereed contributions are inferior to refereed ones but merely that refereeing is not appropriate or not wished by the author.

As a result there will be three categories of paper appearing in the Journal.

a) Papers submitted to the Honorary Editor and subsequently refereed.
b) Conference papers and proceedings not generally refereed but may be if the authors so request and the refereeing procedure can be completed before the Conference Report is due to be published.
c) Mechanisation and review articles not normally suitable for refereeing.

These new procedures will put extra pressures on authors and referees and the Editorial Panel asks for the co-operation of the membership in producing a Journal appropriate to the professional standing of agricultural engineers.

JGS

Energy conservation and alternative sources for the glasshouse industries

K E Morgan

Introduction

VARIOUS factors have reduced the profitability of the glasshouse industries of many countries (Morgan 1980). Since one common factor is the increasing cost of fossil fuels for heating, considerable experimentation and development aimed at reducing heating costs is taking place especially in Europe and North America (Brundrett *et al* 1978). This interest and activity has resulted in numerous proposals and the adoption of several proven techniques. These include the east-west orientation of glasshouses to maximise solar receipts in winter; Venlo-type houses to reduce height and hence the volume of air which must be heated; larger glazing panels on slimmer structures and neater guttering to reduce shading. Heat losses are reduced by the planting of shelter belts, the use of plastics windbreaks and the use of double skins, some of which are filled with foams at night. In Canada steam pipes which previously ran in the ridge of the roof have been replaced with floor level pipes allowing plants to benefit from convected heat. In several countries fans are installed which blow warm air from the roof back to ground level to reduce the temperature gradients resulting from convection. In this country the main development is the fitting of thermal screens, which are drawn over the crop at night to reduce convective losses.

Conventional heating systems are being made more efficient by better insulation, by the use of automatic flue dampers and the overall performance of glasshouses and their heating systems are being further improved by electronic systems which accurately monitor and control temperature and allow better, though still imperfect, control of ventilation. Computerised control systems are available which take into account prevailing and predicted weather conditions (Butterworth 1979).

Changing management techniques include the use of root-zone warming systems, lowering air temperatures — especially at night — and growing low-energy varieties of crops more tolerant of lower temperatures. More care is taken to replace cracked and broken glazing and glass is cleaned at shorter intervals to maximise solar receipts. All these measures are capable of saving some heat, though some are expensive and some have considerable side-effects. All of them have been widely discussed in available literature (Rees and Hand 1980) and there seems little point in repeating the discussion here.

Concurrent with and complementary to the interest in heat conservation has been the search for other sources of heat — including the so-called "alternatives" to fossil fuels — which might be cheaper than conventional heat sources now or in the future. Amongst the sources which have been tried or proposed for glasshouse heating are waste heat from power stations and processing plant, geothermal heat, methane produced from organic wastes, wood, straw, supplementary solar panels, long-term heat storage systems and wind energy systems. Of these sources waste heat appear to offer the most promise to growers, since industries producing waste heat are widely distributed in the UK and many are commercially minded. Heat from this source should be cheap but high capital costs may be involved in bringing heat from the point of production to the point of use. Alternative energy sources, like heat conservation techniques, have been fully discussed elsewhere (Lewis 1980, Morgan and Bather 1980, Penman 1970) — indeed the literature proliferates faster than it can be read — and again there seems to be little point in further repetition.

Instead it is proposed to attempt to describe a very personal approach to energy problems and to describe one minor practical application which promises to be of some value to the glasshouse industry. To condense this into one paper necessitates generalisations, assumptions and over-simplifications which may offend specialists in various disciplines and the use of definitions which may not be wholly satisfactory but which will, it is hoped, avoid both ambiguity and pedantry.

Energy

This widely misused word describes a state of excitation of sub-atomic particles, atoms and molecules and their location and velocity, which permits the extraction of "work", heat and light and which will drive chemical and physical processes. Many energy sources exist which vary widely in their usefulness, convenience and "availability", according to their application and the conditions under which they are applied, their energy density and the energy flux which can be extracted. Energy sources are sometimes described as "renewable" or "non-renewable", though strictly no source is indefinitely renewable. Whatever the form of energy source, the energy it contains can be considered to have originated from one of two fundamental types of process, nuclear and gravitational. Energy originating from nuclear sources includes —

(a) that resulting from human activities in atomic physics — popularly "nuclear energy". For all practical purposes the first useful product is heat energy obtained from fission processes;

(b) that resulting from naturally occurring fission processes — for example, some fraction of geothermal energy, again manifested and extracted as heat energy;

(c) that resulting from naturally occurring fusion processes — that is solar energy and some fraction of starlight.

Gravitational energy is found in tidal systems; other energy forms are due to the residual effects of the formation of the world, itself due ultimately to gravitational forces acting on particles in space.

Solar energy

Of all these sources the one which dwarfs the others into insignificance is solar energy. Some two weeks of insolation represents as much energy as was contained by all the oil, coal, natural gas and peat ever laid down in the earth's crust. All our heating and lighting systems merely supplement current solar receipts, for without them the Earth would rotate in continuous star-lit night with a surface temperature approximating to -270°C. Furthermore it would be necessary to distil and electrolyse sea water to provide fresh water and oxygen and to distribute both as required. In the UK current solar receipts amount to some 16 million kW hours per hectare per annum (say 2000 tons of coal equivalent per hectare per annum), two thirds of which are received as radiation and one-third of which is the energy used to provide rain. Not even deep methane (if it exists and can be extracted) or controlled fusion (if it can be achieved and sustained) can compete with this energy source.

The surface of the sun has a temperature in excess of 6000°C.

K E Morgan BSc NDAgrE AMASAE FIAgrE is Lecturer in Agricultural Engineering, University of Reading.

Consequently it radiates short wavelength energy which, although reduced by dispersion and interception to relatively low power levels at the Earth's surface (up to about 1 kW/m²) is, nevertheless, high grade "available" energy and "renewable" with an adequate flux for a variety of applications. It is also independent of transport and distribution systems. Some of this energy is captured for hours by soil warming. A great deal is captured for 10-15 days by the evaporation of water — far more than the world's total use of supplementary energy. Some is captured for years as biomass and some for geological ages as fossil fuels. Ultimately all this energy — together with the residual heat from other sources — will be re-radiated to outer space, which is at about -273°C, as long wave radiation (see fig 1).

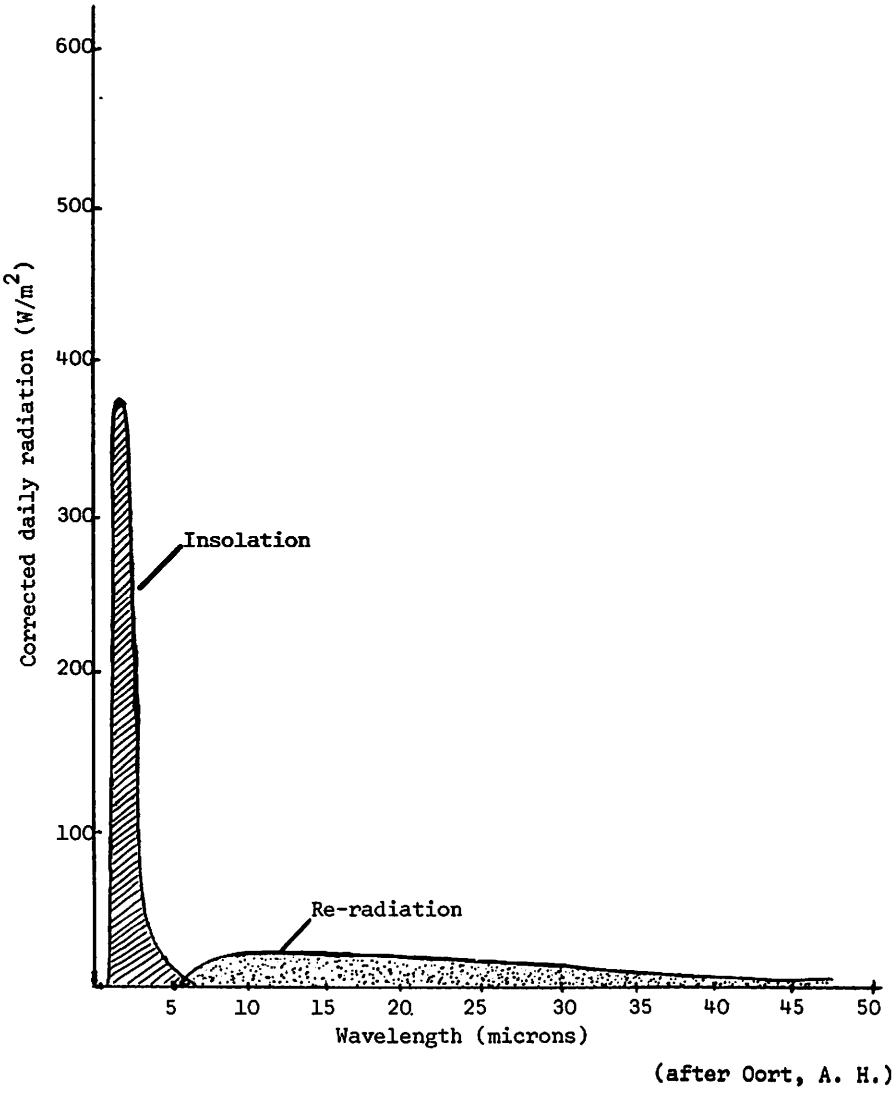
Living organisms utilise this natural entropic path, diverting the incoming to outgoing energy flow through themselves, though in the final analysis the beginning and end points are unaffected. Man has learned to manipulate some of these diversions to serve his own purposes — agriculture and the internal combustion engine are two examples. The energy received and the energy re-radiated by Earth are kept in balance by various physical mechanisms so that temperatures on Earth are stable; differences between countries and seasons are very small compared with the range of temperatures which can be produced. The Stefan-Boltzmann 4th power law — that radiation varies as the 4th power of the temperature of the radiating body — indicates the magnitude of the stabilising factor.

Latent Enthalpy

Considering that a large fraction of the surface of the Earth is covered with water, wet earth and transpiring vegetation and remembering that vast quantities of energy are received by this cover, it is not surprising that the atmosphere contains a lot of water vapour (Penman 1970). What may be surprising is the amount of energy that this water vapour represents. Evaporation at ambient temperatures and pressures requires some 600 calories per gramme — ie 11% more than is required to produce the same phase change at 100°C at one atmosphere. These phase changes are reversible, so that energy taken up as water evaporates is given off as the water recondenses. The fascinating implications of this are:—

1. at any one time the atmosphere contains over 1000x the world's total use of supplementary energy;
2. this latent energy is renewable, since condensation would result in a lower relative humidity (RH), leading to increased evaporation, which could cause a slight drop in temperature, hence there would be considerably less re-radiation and temperatures would recover;
3. the potential energy flux is enormous. Of course it is known that these phenomena drive such energetic systems as hurricanes, but even so the figures are surprising. A column of air 1 m² in cross section moving at 10 m/s and having a temperature of 25°C and an RH of 50% contains energy equivalent to 478 kW (continuous). The same air at 100% R H contains energy equivalent to 763 kW. If the key to unlock this vast energy store could be found — more prosaically, if the energy could be made available — the prize would be hundreds of thousands of years of free, non-polluting power.

Fig 1 Reception and re-radiation of solar energy



(after Oort, A. H.)

Plants

One aspect of this relates to plants. Very small fractions (some 1%-4%) of the solar energy received by a plant are used to drive photosynthesis, whereas a large fraction (usually in the range 40%-60%) is used to evaporate water in transpiration. Thus a plant is a combination of a self-developing well, a pump and motor, a flat plate solar collector and a porous plate evaporator. It is efficient, self-constructing, self-maintaining, self-supporting, self-cleaning and self-renewing. Phototropic plants contain their own heliostats, the whole device is energetically cheap to produce, contains only minor quantities of scarce or expensive metals and often has considerable scrap value. Plants also produce carbohydrates as a by-product.

Again the scale of these operations is impressive. A large, free-standing tree may be using solar energy at rates up to a megawatt, a lawn tennis court may be utilising 450 kW and a hectare of tomatoes may transpire 5500 tonnes of water during its growing period, taking in some 3 million kW h of heat to evaporate the water.

Of course the plant itself must be kept at a suitable temperature if it is to survive and continue to photosynthesise, transpire and grow, although plants and the soil and air surrounding them are continuously rejecting heat which is radiated away to outer space. In hot climates — or in the UK in summer — plants and soil receive vast excesses of solar radiation and the prodigal waste does not matter. The energy is free and enough heat will be retained overnight to prevent the plant from freezing. In cooler climates many plants have adapted to lower solar receipts and can survive freezing, but there are good reasons for wanting to grow plants outside their natural habitat or season.

Glasshouses

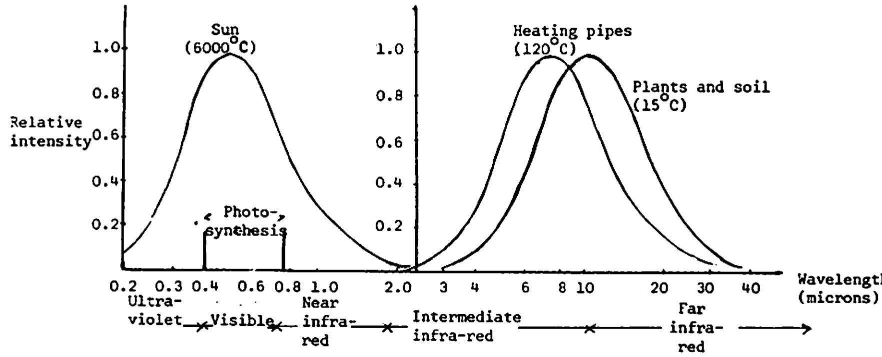
To isolate plants from an unfavourable climate it is necessary to provide an insulating structure. Supplementary heating has, in the past, been easier to provide than adequate lighting, so the conventional glass-glazed house evolved. This certainly admits natural light, but as a heat-retaining structure it is about as useful as is a sieve for holding water. Consequently it seems that calculations about the heating requirements of a glasshouse are as useful as calculating the water supply needed to fill a colander. Unfortunately, a great deal of respectable research — for example, the development of mathematical models of glasshouses or the relating of windspeed and heat losses — has only historical interest, since it is concerned with obsolete structures.

In addition to admitting visible light — more importantly, the photosynthetically active wavelengths within the visible spectrum — glass is transparent to short wave heat radiation (eg near infra-red from the sun) but is opaque to the long wavelengths re-radiated from plants and the surrounding soil (see fig 2). Hence solar radiation is trapped, producing the temperature rise known as the "greenhouse effect". It is interesting to compare a graph of the spectral transmission properties of glass which show a sharp cut-off at 4.5 microns, with the graph given in fig 1, since this indicates just how effective glass is as a one-way valve for heat.

But glass is brittle and heavy and requires substantial supports which cast shadows; it is a poor thermal insulator in the thicknesses used and the many separate panes are difficult to seal. Thus a conventional glasshouse leaks heat by conduction and convection and loses sensible and latent heat as warm wet air escapes. These losses continue round the clock so that in winter, when insolation may be limited to eight hours duration and its intensity is reduced by cloud cover and the low angle of the sun, it is no longer possible to maintain desired temperatures without some form of supplementary heating.

While heat was cheap the losses could be made good and almost unwitting advantage taken of the ventilating effects of a leaky structure. This reduced over-high humidities, lessened carbon dioxide depletion and prevented air stagnation. Involuntary ventilation caused problems with carbon dioxide enrichment, but then carbon dioxide was cheap. Glass-glazed houses exhibit another characteristic causing heat losses. Because glass is a poor thermal insulator it is "cold" and condensation forms on the inner surface. This condensate is largely removed by the overlapping unsealed joints between panes acting as capilliary pumps. The heat given up by the water vapour as it condenses is conducted through the glass where it helps to re-evaporate the water pumped through the joints. To reduce these losses sealable glasshouses have been built, but these are subject to all the problems associated with over-high humidity — condensation causing conductive heat loss and interference with light transmission, drip damage to plants, puddling on thermal screens, and an atmosphere favourable to fungal diseases and in some cases unfavourable to pollination.

Of course, these sealable houses can be deliberately vented either to reduce the temperature, or the humidity, or both. Ventilation appears to serve three purposes — to throw away sensible heat, or to throw away latent heat, or both.



(after Turral, H.)

Fig 2 Spectral characteristics of objects radiating at three important temperatures

Various materials have been proposed as replacements for glass (Clayton 1979, Turral 1980). Polyethylene is cheap and can be used to construct sealable structures, but its life is short and its spectral transmission qualities are unsuitable. Polycarbonates have a better life expectancy and better transmission properties. They can be formed into large sheets and allow the use of less substantial supporting structures. Like the polyethylenes they require ultra-violet stabilisers to reduce the degradation caused by sunlight; they are good thermal insulators but they are subject to crack propagation, the commercial brands are expensive and they are relatively inflexible. Many other materials have been proposed but the most promising appears to be Melinex OW. This is tough and flexible, it is a good thermal insulator and has excellent spectral transmission qualities. It has narrow band opacities at 2.9 and 3.4-3.5 microns which will reduce incoming radiation, but not in the photosynthetically active wavelengths. It lacks the sharp cut-off shown by glass at 4.5 microns but is, nevertheless, almost as effective in producing the greenhouse effect. It is relatively cheap, the UV stabilised material has a life expectancy of 15 years in NW Europe and it is available in large rolls. It can be repaired if it is cut and is heat shrinkable. One obvious application is to wrap it round the outside of conventional glasshouses to "double glaze" them.

The Variglaz greenhouse

This is the product of a joint venture between ICI Limited and the Cambridge Glasshouse Company. Large, sealed, double skinned Melinex panels are used which minimise shading. At night the panels are inflated to maximise thermal insulation, but during daylight the skins are sucked together to maximise light transmission. Early versions had the touching surfaces of the panels coated with dimethyl silicone, so that the two Melinex skins behaved optically almost as one skin, but a new grade of Melinex has been produced recently which is water wettable (Ward 1981). This allows water to join the touching surfaces. It also has a beneficial secondary effect on light transmission, since droplet condensation which interferes with light tranmission is eliminated and condensation takes the form of a thin transparent film. This type of house has shown itself capable of saving 40%-60% (depending on windspeed) of the fuel needed by a conventional glasshouse. It is thermodynamically very different from a conventional glasshouse and has required a complete re-appraisal of management techniques. Whilst it is sealed it can create problems of excessive humidity and very high temperature lifts, but it is the starting point for a totally new concept — a greenhouse which is not a structure but rather a machine reacting "intelligently" to its environment.

The Sciray house

This is a development from a large consortium which includes ICI Ltd and the Cambridge Glasshouse Company, but also includes York Borg-Warner, Agritron Ltd and Agri-Projects International. It brings together two concepts — the Variglaz glazing system and temperature and humidity control by refrigerative de-humidification. This approach to the control of the environment in a greenhouse has been the subject of five years of research at the University of Reading (Cooper 1980, Bird 1976). It has been described in the literature (Morgan 1980) and publicly exhibited at the Royal Show in 1979 and the Great Yorkshire Show in 1980. It is, therefore, unnecessary to do more than outline the principle. This is that by recondensing transpired water vapour latent heat can be recaptured and transformed into sensible heat. At the same time as the heat is re-cycled so is the water, and since this is distilled it provides a high purity source for NFT systems or for other purposes (Morgan 1979).

The Sciray house is an integrated energy management system. The skin can react differentially according to the net passage of energy across it — so that on a cold winter's morning the east face may deflate before the west face, whilst the north face may remain inflated all day. The heat pump has enthalpy sensors which allow it to select the heat source from which it can work more efficiently over a given period. This system operating in a different application but with similar parameters has worked consistently at coefficients of performance of 6+ — ie efficiencies in excess of 600% (Turbard 1981). The whole system is controlled by a mini-computer developed by Agritron Ltd, which senses internal and external temperatures and humidities (thus being able to calculate relative enthalpies), wind speed and direction, insolation, time of day, the date, predicted weather conditions, and so on. The logic by which this information is used to arrive at the best control strategy has been developed at the University of Reading and within the consortium. The first version of this house is being built at the ICI establishment at Fernhurst and will be used to grow long-season tomatoes this year. It is expected that limited numbers of Sciray houses will be commercially available from the late autumn of this year.

The greenhouse of the future

Theoretically it would be possible to build greenhouses which were capable of maintaining blueprint temperatures in the UK without supplementary heating. However, light is a limiting factor in the UK in winter, so that supplementary lighting would be required to optimise plant growth. As additional heat requirements are reduced so the "waste" heat from artificial lighting becomes a larger fraction of the heating load, and under these circumstances artificial lighting becomes highly efficient. It is possible to imagine a development of the Sciray house which requires no heating other than the waste heat from lighting and from the prime mover driving the heat pump, and which promotes earlier crop maturity with little extra cost.

The glasshouse industry exists to serve a luxury market and so long as customers are willing and able to pay a premium for out of season or superior quality fruit, flowers and vegetables, this market will continue to exist. In spite of the EEC, and in spite of some sympathy for glasshouse industries abroad, our prime duty is to the UK industry. It is hoped that some of these developments will help to sustain it through the difficult years which lie ahead.

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A personal computer for glasshouse environmental control

S W Burrage

Summary

IN this paper the development of an automated glasshouse control system based on the PET personal computer is discussed. Details are given of system configuration, sensors, and software development.

The control of glasshouse environments has been principally by individual analogue controllers providing on/off or proportional control. For each additional development of the glasshouse complex more controllers are required and little centralisation of control systems is possible. Limited integration with other systems eg ventilation and CO^2 addition, can be achieved, but generally only on a simple ON/OFF basis. Sensing normally takes place at a single point within each glasshouse and few controllers take into account the external environmental conditions. The analogue controller provides no indication of performance or record for the operator. It is difficult, therefore, with a system of this type to construct an integrated system of control. Following the escalation of fuel costs and the proportional increase in energy as part of production costs, considerable pressure exists in the glasshouse industry to improve the efficiency of energy usage. While this can be achieved in part by improving the performance of the analogue controllers, optimum performance will only be achieved by truly integrated control, where the operator can not only take into account the heat balance of the structure, but also the inter-relationship between environmental factors and plant growth (Takakura 1973; Challa 1976; Bot and Dixhoorn 1978).

During recent years we have seen development in computerisation of control of the glasshouse environment, initially in Holland (van de Vooren 1975; Udnik ten Cate and van de Vooren 1978) and more recently in the United Kingdom (Weaving 1980). This has coincided with the development of more dynamic models of glass-house climates. Computer control systems provide the operator with immediate status indication, allowing detailed assessment of system performance. This rapid feedback of information to the operator improves the efficiency of each glasshouse, allowing the evaluation of the unique characters of each unit.

In the autumn of 1979, work began on a computer control sysyem at Wye, based on existing 'off-the-shelf' modules. It was designed to form the basis of a commercial system, to have facilities equal to the available commercial glasshouse computer systems, but with more flexibility, allowing the operator to develop the system to his own requirements. The key factors of the operation were low cost and high flexibility. An outline of the system is shown in fig 1. The system is required to control the environment within 3, ¼ ha glasshouse blocks, regulating temperature, CO^2, a nutrient film system (conductivity, pH and solution temperature), irrigation and, at a future date, thermal screens and daylength blinds.

The system layout

THE Commodore 3032 personal computer (PET) was chosen as the basis for the system. These computers are already in extensive use, are relatively low cost and easily available and have considerable supporting software and compatible hardware. Programmed in Basic, a relatively easy language to learn, the computer has, user available, 32K of memory. This is more than adequate for our present system, which uses 17K, leaving considerable space for future development. The computer is linked to the sensor and control units through a 32 channel I/O interface unit manufactured by 3D, Digital Design and Development. This is connected to the IEEE/488 bus and provides 32 channels of single-ended analogue inputs. Input voltage range is set at 0 ± 2.5 volts with 8 bit resolution (1 in 256) and with 1.5 M input impedance. There are 32 output channels of spst relays with 100V, 0.5 amp capability. A light-emitting diode on the front panel indicates the function of the relay.

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Power for the sensors is provided by a ± 12 volt IA power supply within the interface unit.

The interface unit is linked to the meteorological station mounted above the glasshouse and to each of the houses via 25 twisted pair 0.5 mm solid cables. The length of run for these cables is from 50-150 m. From a junction box in each house, the main cables are linked to the various sensors. Control signals are connected to the existing analogue controllers through mechanical or solid state relays. A changeover switch allows the system to return to analogue control should this be necessary.

A Commodore 3022 tractor printer is used to give hard copy records and to record alarm warnings. An alarm relay on the interface box is linked to an alarm bell and provision is made to link with an automatic telephone dialling system. A cassette recorder is used to input programs.

Sensors

The effectiveness of the control system is dependent upon the accuracy and reliability of the sensors. Unfortunately, the development of sensors has not been as rapid as the development of computer technology to lower their price to levels suitable for the glasshouse control system. Where possible ready-built sensors were purchased, however, in the main, sensors were developed specifically for the project.

Above the glasshouse, a meteorological station made up of windspeed, wind direction, temperature, radiation and rainfall-detecting instruments monitors the external environment. Within each house a ventilated psychrometer unit monitors air temperature and humidity; potentiometers are used to detect ventilator and steam valve positions. In

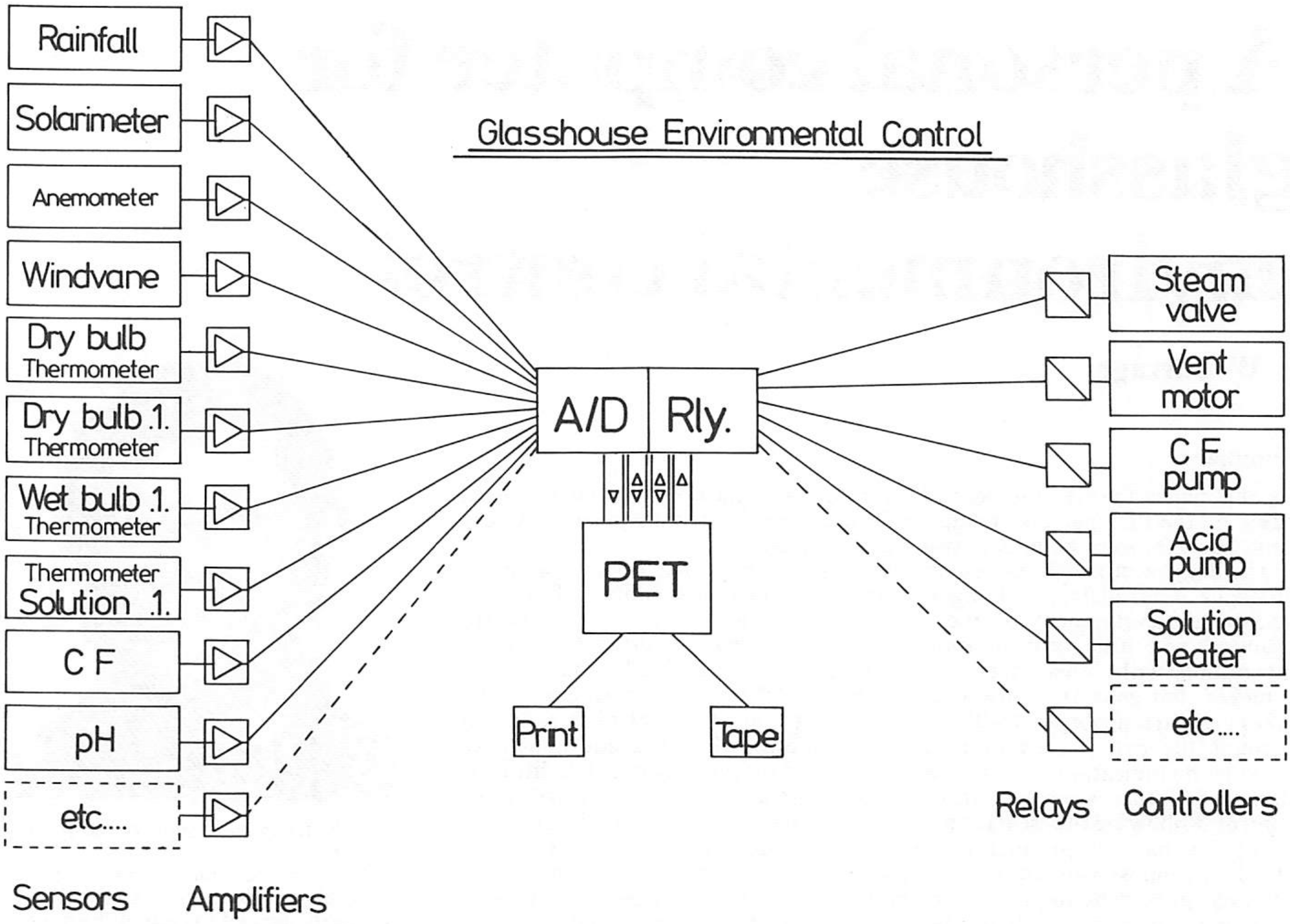


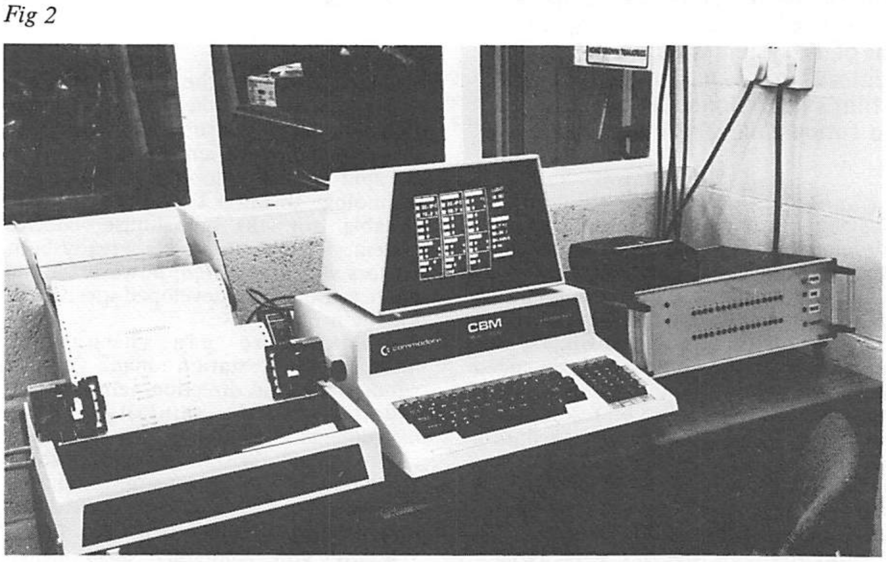
Fig 1 The Wye personal computer glasshouse control system

the nutrient film system, electrical conductivity is used to determine nutrient status, pH to determine acidity and solution temperature for solution heating control.

Each sensor is connected directly to a small, resin-potted amplifier module where the signal is amplified or attenuated to match the 0-2.5 V input requirements of the A/D interface. The gain of the system is adjusted to give maximum resolution over the anticipated range, eg air temperature measurements have a 50°C range, having 256 bit resolution, this sets the maximum definition at 0.2°C. Voltages outside the range -0.2 — +2.8 V are avoided as these produce interference in the A/D unit, not only on the affected channel, but on all channels.

To avoid hunting in the control system, the response time of the thermometer sensors was adjusted by increasing size to 5 mm giving a 10 second response time for a 10°C swing in temperature. This technique is not possible with radiation sensors where readings are integrated over a 30 second period by integration techniques within the electronic module.

Fig 2



The computer

The sensors are scanned every minute, each sensor being scanned 5 times for each reading. The readings are displayed on the video screen. These are in an alphanumeric form on a graphic outline of the three houses with status record (ON/OFF) for vents, steam valves, pumps, etc. This display gives a direct indication of the status within the houses (fig 2). When a control function is operated, eg the opening of a steam valve, the position of the control is checked every fraction of a second until the prescribed position is reached. The valve is then stopped. This enables more precise control functions, avoiding overshoot. The computer clock is used to control all the timing functions of the system, including nutrient addition and daylength treatments. The changeover from day to night and vice versa is determined by the level of radiation.

Single-button selection allows alteration of pre-set conditions and alarm limits. The normal operation of the system can be over-ridden at the keyboard while retaining full monitoring. A hard copy of mean data is recorded on the printer with more frequent records being made on the cassette recorder. The cassette data can be processed on a second PET system in the laboratory.

Software

The programs for the system are in PET Basic. Although this is slower than machine code, this is adequate for efficient operation of the system. There are areas where the higher speed of machine code might improve sampling, 20 rather than 5 readings for each sensor, but with little experience in machine language, this at the present time was not possible. Its introduction into the system might also inhibit the development of the system by less experienced operators. The program was developed as a series of blocks so additional software and expansion of the system, eg thermal screen control and other sections of the nursery, could be accommodated within the existing program.

It is not possible in so short a paper to discuss at length the actual program. To give an idea of the complexity of the program, one small section concerned with the control of ventilation is shown in fig 3. The question that has been asked is "Is air temperature greater than set vent temperature?" The reply is "Yes". The first process is to check over-rides to see if manual control is in operation. Next to see if the steam valve is closed. Windspeed, wind-direction, inside and outside temperatures are used in the calculation of the required opening to give appropriate control of temperature. This value is compared with the maximum and minimum limits to ensure that it is within these, then the previous setting is compared; if this is greater than 5% then the ventilators are allowed to move. This avoids hunting of the system resulting from a requirement for only small changes in ventilator opening. The opening or closing of the vents is initiated and the progress followed at approximately one-tenth of a second intervals until the prescribed value is reached. Indication of the operation is recorded on the VDU screen with an indication of the percentage opening. At the completion of the operation, control is returned to the main program until the next one-minute cycle. This process is carried out simultaneously for each of the control functions, steam valve position, conductivity, etc.

Discussion

In trials at Wye, the system has performed well. In the future it is planned to improve some aspects of the system. A stand-by battery system will be introduced to prevent memory loss in event of power failure. In future systems, a 12 bit A/D converter will be introduced to allow more flexible sensor development. We see continued sensor development as an important part of system development and we intend to introduce new sensors into the system as they become available. The development of new techniques and increased mechanisation in glasshouse production will increase the need for use of computer techniques for control. A good example of this is the development of NFT and its increased introduction in the industry. At present, conductivity sensors are used to determine nutrient status of the solution. This is an inadequate measurement as nutrient and non-nutrient ions in solution are given equal value by the sensor. In the future, selective electrodes, capable of operating under commercial conditions, may be developed enabling individual nutrients to be added to the solution. Using computer monitoring and control will enable a proper balance of nutrients to be maintained in solution.

The development of a computer control system in the glasshouse at Wye has allowed us to optimise the operation of existing controls. With high cost of fuel and the relatively low cost (£4000) for the system we can justify its installation for this purpose alone. Its installation, however, will allow us to develop a more integrated environmental control system including light-linked temperature control and light-linked irrigation systems. This will enable us to obtain optimal growth of the crop in the short term. The challenge of the future is to bring together the short-term control of growth into an overall strategy of plant production.

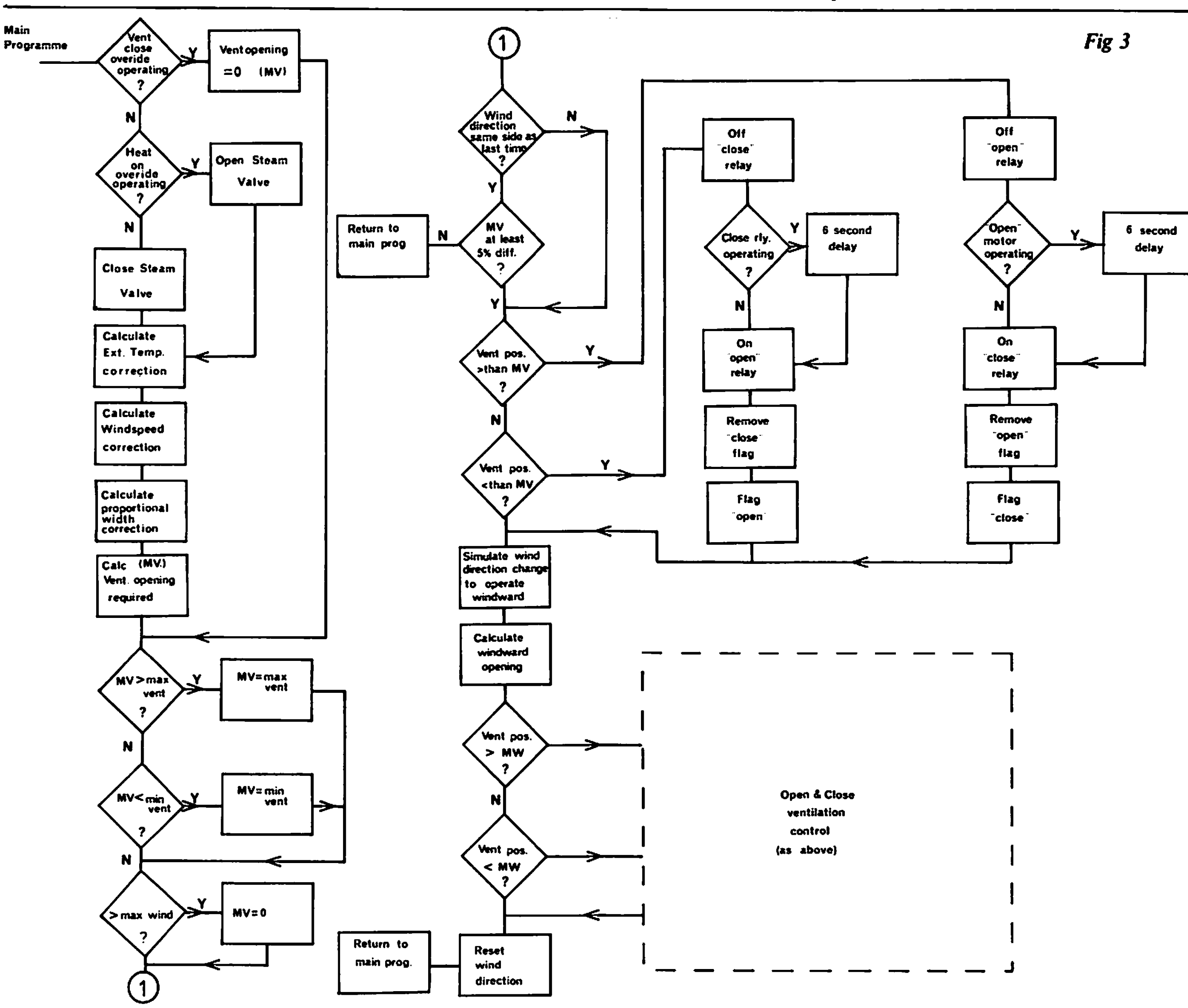


Fig 3

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Crop protection in glasshouses and orchards

R A Umpelby

Summary

A REVIEW of the methods of pest and disease control currently used in glasshouses and orchards is given. The results of mechanical and biological monitoring of orchard sprayer performance are presented. The need for co-operation between biologists, chemists and engineers to obtain the maximum pest and disease control for the minimum input of pesticide is emphasised.

Introduction

IN theory the relatively controlled environment of a glasshouse should make pest and disease control easier on glasshouse crops than on outdoor crops. In practice the intensive cropping and close planting results in a very difficult spray target and many pests and diseases, which are seasonal on outdoor crops, are able to thrive throughout the year. Resistance to pesticides is commoner with glasshouse crops than with other crop groups.

Efficient spray application in orchards is probably more difficult to obtain than on other outdoor crops due to the compromises necessary in sprayer design to allow for the wide variation in tree height, row spacing and pruning techniques which result in very different spray targets. Orchard spraying is considerably influenced by wind because the spray has to be directed up into the tree canopy. The distance between the spray nozzle and different parts of the spray target may vary by a factor of 20 but equal spray deposits are normally required throughout the target.

Usage of insecticides and fungicides is greater, per hectare of crop, on glasshouse and orchard crops than on any other crop group except for hops (Sly, in the press), and the methods of application used to apply pesticides to glasshouse crops are more varied than any other crop group.

Development of crop protection

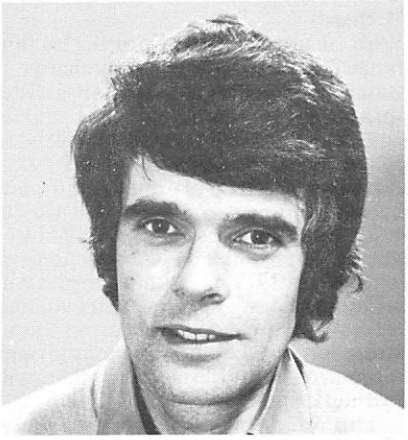
Although the major developments in crop protection have occurred in the last 40 years, as early as 1000 BC Homer recorded the use of sulphur to control pests and the insecticidal properties of arsenic were known in China before 900 AD (Fletcher 1974). During the 17th century tobacco extract was being used to control peach pests in France and in England by 1773 for aphid and red spider mite control. Other natural pesticides became widely used in the 19th century including copper, derris, nicotine, quassia, sulphur and inorganic oils; usage of some of these pesticides continues today. Since 1940 a series of synthetic organic pesticides have been developed culminating with the current series of systematic fungicides and the synthetic pyrethroid insecticides.

The development of application machinery has not matched the recent rapid development of pesticides with few new major techniques being introduced since 1930. The earliest methods of pesticide application were with a brush dipped in the spray liquid and flicked over the plant (Lodeman 1896), this technique was later mechanised with a revolving brush (Large 1940). The 'watering can' principle followed and then a type of syringe was developed to give a hand-powered force pump which was mounted on a trolley. Sprayers where the forward motion of the wheels drove the pump were soon replaced by steam pumps which were either static or horse-drawn. Steam pumps were replaced by the internal combustion engine and by 1933 the forerunners of todays mobile, self-powered or tractor-drawn, air-assisted orchard sprayers were developed in USA (McIndo 1943), these became widely used in England in about 1950 when they replaced the purely hydraulic sprayers.

Current methods of pesticide application

Glasshouses

The majority of pesticides are still applied as sprays but in glasshouse crops various other methods are used. Table 1 shows the percentage of the total area treated with pesticides treated by the various methods of application in 1976 for some major glasshouse crops. The table shows



that different crops are treated by different methods according to their growth habit and the ease of application, for example cucumbers receive a high proportion of drench treatments whereas smokes and fogs are more widely used on mushrooms.

Sprays in glasshouses have traditionally been applied at high volumes with hand lances or sometimes with fixed spray lines, volumes of water applied may exceed 2500 l/ha. More recently ultra-low volume (ULV) sprays have become widely used, often spray volumes of less than 5 l/ha being used. ULV sprays are normally applied as pre-formulated oil-based applications through a small hand held machine with a spinning disc nozzle. The machine has a small electrically or engine driven fan to carry the spray to the target and the spinning disc nozzle is driven by a turbine in the air stream, or sometimes directly from main fan drive. The average spray droplet diameter can be as low as 30 μm. A limited use of aerosol sprays is recorded, again with oil-based pesticides, but these produce droplets of less than 10 μm diameter. Even smaller droplets are produced by fogging machines where the spray 'particles' are produced in the exhaust gases of a small engine. The use of fogs for pesticide application has

Table 1 Glasshouse crops, method of application of pesticides, percentage of total spray area

Crop	*Method of application*						
	High volume spray	*Low volume spray*	*ULV spray*	*Fog*	*Smoke*	*Dust*	*Other methods*
Lettuce	51	2	8	1	1	23	14
Tomato	33	1	10	16	6	1	33
Cucumber	46	7	3	3	4	2	35
Pot plants	43	4	24	1	6	1	21
Mushroom	21	0	1	23	22	10	23
All crops	47	2	8	6	5	10	22

(From Umpelby and Sly 1981).

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increased over the last few years due to the ease of application but the pest and disease control achieved is not as good as by conventional spraying. Other methods of application used in glasshouses include baits, biological control, drenches, dusts, granules, soil sterilisation/flooding and application through irrigation systems but all of these are used on a limited scale.

Orchards

With few exceptions insecticides and fungicides are applied to orchards as water-based sprays by air-assisted sprayers. The volume of water applied has been reduced from the 5050 l/ha recommended by the Ministry of Agriculture in 1930 (Turnbull 1930), with hydraulic sprayers, to the current 450-800 l/ha used by most growers. Table 2 details the water volumes used in orchards in 1979 on culinary apples with some pesticides. The lower water volumes used today are possible because the air stream penetrates the tree canopy giving a more even spray distribution than with hydraulic spraying.

The modern orchard sprayer is normally a trailed machine with the fan and pump being powered by the tractor pto. Tank sizes vary between 700 and 1500 litres capacity for trailed machines, mounted sprayers do not exceed 600 litres capacity. The pump on earlier sprayers was normally the piston type but diaphragm pumps are now widely used. Nozzles are normally of the hydraulic swirl-plate type and are constructed of plastics, brass, stainless steel, tungsten alloy, ceramic or saphire ('Saphite'). The abrasive nature of pesticides formulated as wettable powders causes very rapid nozzle wear to the softer nozzle materials and frequent replacement is necessary.

The fan is usually the axial flow type but some sprayers have centrifugal fans. Due to the close planting distance in many orchards narrow tractors with total engine power of less than 35 kW are normally used and this can restrict the size of sprayer, according to its power consumption, which can be used.

Other methods of application of pesticides to orchards are limited to the use of paints applied directly to wounds on the tree, and application through irrigation systems, either trickle or overhead, or misting systems, but all of these are used on a very limited scale.

Performance of orchard sprayers

In 1979 a series of measurements were made on some of the orchard sprayers available in Great Britain. Air outputs of the sprayers were measured in accordance with British Standard 848 (Anon 1963). Power requirements of the sprayers were measured with a pto torque transducer with direct reading instrumentation giving pto power requirement, torque and r/min. A Scholtz linkage and indicator system was fitted to the tractor drawbar giving the draught drawbar pull power requirement.

Table 3 gives the mean air speed and total air volume produced by each sprayer and the total power requirement when travelling at 6.0 km/h on a firm, level grass surface with the sprayer fully laden and the pump set at maximum pressure.

Table 2 Culinary apples, volume of spray applied, percentage of total spray area

Pesticide	*Spray volume (litres per hectare)*					
	55–220	*220–450*	*450–800*	*800–1350*	*1350–2250*	*>2250*
Azinphos-methyl	19	10	45	11	15	0
Demeton-S-methyl	4	13	63	8	11	1
Dinocap	31	4	45	9	10	1
Mercury	1	31	41	14	13	0
Mean all pesticides	5	16	56	10	12	1

(From Umpelby and Sly, in print).

Table 3 Orchard sprayers, air outputs and power consumptions

Sprayer	*Fan* type*	*Air volume (m^3/sec)*	*Air speed (m/sec)*	*Power consumption** (kW)*
1	A	15.9	24.7	24.5
2	A	14.6	37.8	40.7
3	A	12.3	36.1	22.6
4	A	12.1	34.7	29.8
5	A	10.6	18.6	26.0
6	A	9.5	19.4	21.3
7	A	9.3	33.3	29.8
8	A	8.2	24.7	24.6
9	A	6.5	31.1	19.9
10	C	4.4	61.7	24.6
11	C	3.6	33.1	21.7
12	C	2.1	55.6	25.4

* *A = axial flow, C = centrifugal.*

** *See text, all power consumption data was supplied by M Wilkes (Wye College).*

The results of the tests showed greater variation between the measured performance of some of the sprayers and that claimed by the manufacturers than would be expected due to normal manufacturing tolerances. This variation may be due partly to some sprayer manufacturers using non-standard measuring techniques but may also reflect the absence of independent sprayer assessments, similar to those carried out on tractors by the Organisation for Economic Co-operation and Development (OECD).

The tests indicated that the power requirement of some sprayers, when run on demanding ground conditions, may exceed the power available from tractors normally used for orchard spraying. The tests also showed that high power requirements were not necessarily reflected by high air outputs. The main causes of high power consumption were poor, or total lack of design of air outlets, causing air turbulence and hence higher power requirements for a given air output, or pumps with excessively high power demands.

Biological evaluation of orchard sprayers

Mechanical differences in sprayers are easily demonstrated in static tests but the ultimate test of a sprayer is its effect on pest and disease control in the orchard. In a series of replicated trials, each run for two years, different spray machines were used to apply the same spray programme to apples under as near identical conditions as possible. Each machine was used to apply a full season's spray programme using the same rates of pesticide per hectare, in the same volume of water and at the same ground speed. All pest and disease incidence was monitored but only apple mildew *Podosphaera leucotricha* was severe enough to give meaningful results.

Table 4 shows the level of secondary mildew infection recorded in plots treated with different sprayers, the sprayer number refers to the same sprayers as in table 3. The results shows that the sprayer with the highest air volume gave the best control of mildew. This confirms work done by Hale (1978) in which he demonstrated that a better spray distribution was obtained in apple trees when a high volume/low speed air jet was used than with a low volume/high speed air jet. It is possible that if the rates of application of pesticide had been reduced, to give less complete pest and disease control, that more differences in the performance of the sprayers could have been demonstrated.

Table 4 Effect of different spray machines on apple mildew control, percentage of secondary mildew infection

Trial number	*Sprayer number**	*Date of assessment*		
		June	*July*	*August*
1 (1978)	1	61.0	20.0	4.7
	12	62.2	48.3	10.00**
2 (1978)	1	17.3	27.8	15.7
	10	29.5	27.5	33.2ϕ
3 (1978)	1	6.0	3.3	2.7
	4	9.8	6.3	4.0
4 (1980)	1	1.7	1.3	0.5
	7	2.2	4.3	3.0
5 (1980)	1	1.8	1.2	1.7
	4	4.3	1.7	3.5

* *See table 3.*
** *Difference significant at $P = 0.01$.*
ϕ *Difference significant at $P = 0.05$.*

Co-operation in research on spray application

Spray application involves the overlap of different technical disciplines. Although the roles of the biologist, chemist and engineer are apparently distinct a close co-operation between them is needed to enable advances in spray application efficiency to be made. The biologist and chemist already work together in evaluating new pesticides but inadequate consideration is sometimes given to how a pesticide can best be applied. The biologist can determine the optimum droplet size for maximum biological effect for a given pesticide formulation but co-operative research with formulation chemists may result in even more efficient usage with perhaps a totally different droplet size given a different formulation of the same pesticide. The development of ULV spraying in orchards is an example of the need for reformulation of certain pesticides to improve their performance when applied by unconventional methods.

To help the engineer design a more efficient sprayer the biologist needs to define the type of spray cover required to give maximum biological effect. The biologist needs to know what limitations will be placed on the results of his work by engineering considerations. If the engineer is unable to produce a sprayer to distribute even-sized spray droplets throughout the tree canopy the biologist will need to know the range of droplet sizes the engineer will have to use to obtain an even distribution of pesticide. Another possible result of co-operation would be selective deposition of spray on parts of the tree attacked by specific pests or diseases, eg some pests only attack shoot tips and maximum pesticide deposit at the site of infection would improve the biological efficiency of the pesticide.

Different formulations of pesticides will affect the spray droplet spectrum produced by a nozzle, as will changes in dilution of the spray liquid. Co-operation between the chemist and engineer would ensure that a spray pattern with optimum characteristics could be produced.

Without close co-operation between the different disciplines improvements in the design and performance of sprayers will continue to be slow. Excessive amounts of pesticides will continue to be used to compensate for poor spray distribution obtained by sprayers, some of which are produced to suit the convenience of manufacturing techniques and not designed to have the maximum biological effect for the minimum pesticide usage.

Research into the use of electrostatics in spray application (Coffee 1979; Arnold 1979) demonstrates how major improvements can be made when all aspects of spray application are considered together. It is from this type of work that growers will be able to reduce the quantity of pesticide they need to use with the resultant economic and environmental benefits to the whole community.

Acknowledgement

Thanks are due to M Wilkes (Wye College) for the data on sprayer power consumption presented in this paper.

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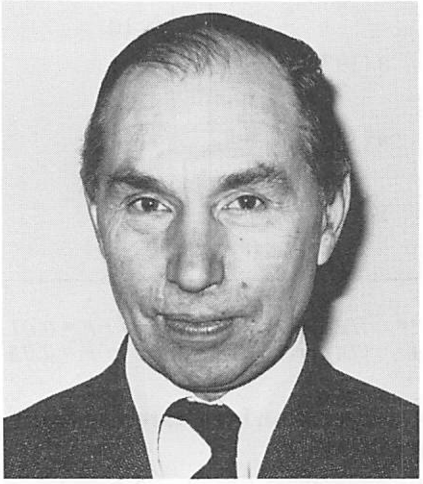
Aspects of mechanisation of the hop crop

M W Shea



Summary

MACHINERY and problems influencing continued mechanisation of hop production are discussed with particular reference to England but also to other major hop producing countries. Particular mention is made of machinery to assist hop stringing, gathering and transport of bines to static picking machines, and mobile harvesters. Some problems associated with crop protection, handling the picked green and dried crop, and drying are also briefly discussed.

THE cultivation of hops has for many centuries been a labour intensive occupation but it has also demanded a high level of technique. It follows from this that the substitution of hand labour by machinery has set numerous problems which have been met with various degrees of success, and some not even tackled.

Since the plant will not flourish unless it can climb vigorously, and the fast growing tissue is vulnerable to insect and fungal attack the current technology of the age has always been called upon to assist in its culture. The costly provision of poles at each rootstock, that used to be placed in the spring and removed each harvest soon caused a search in Bavaria and Bohemia for timber preservatives for the coniferous timber used. Various washes and sprays have been applied against aphid attack for many decades and 'squirts' developed later into horse drawn spray tanks with manually operated beam pumps to spray up to 7 m high with handheld lances.

It should, perhaps, be made clear that the hop plant is a long lived perennial producing complete re-growth of the aerial parts each year. Shoots break ground in early spring and commonly make 7 m of growth in each of several selected shoots per stock or hill by July under English conditions. Only the female plants produce hop cones but in some countries male plants are deliberately included, which, due to pollination increases the bulk of the crop and the yield of brewing material, eg England. In other countries the males, wild or escapes, are rigorously excluded by law.

A hectare of hops, containing some 4500 stocks, will produce 23-28 tonnes of green matter, finally yielding (UK average) 1.75 tonnes of dried hops valued between £2500 and £4250 depending on variety and quality. The only outlet for the crop is sale to the brewing industry, where during brewing the resins in the cones, amounting to 10-25% by weight, impart bitterness and a 'hoppy' flavour. Total farm sales of hops in UK realises £19-20 M/annum.

Cultivation of hops for beer probably started in central Europe in 800 AD. It has spread to at least 20 countries in the temperate zones of both hemispheres and produces some 250,000 tonnes of dried hops.

Twenty years ago hop harvest was accompanied by a surge of casual workers, frequently whole families taking a working holiday, who had to be housed and looked after for three to four weeks each year. When this labour found other summer diversions, many in response to better living conditions, hop picking machines became essential to the industry. Once beyond the development stage picking machines lowered the casual labour requirement by a factor of 8 or 10 and subsequently lowered harvest costs considerably. There is no prospect of repeating that order of labour reduction by further mechanisation but there are several areas where additional machinery can reduce labour and reduce effort in specific tasks.

As a result of a questionnaire sent to hop growers in 1975 it is possible to list those aspects of hop production that they thought most warranted either starting or extending mechanical development. Of the many factors reported the six most repeatedly referred to were:—

- Mechanical assistance in cutting bines from the wire-work and transporting them to the picking machine.
- Need for a mobile picking machine
- Mechanical assistance with stringing the hop garden.
- Improvements in hop drying.
- Improved crop protection.
- Mechanical handling of picked green and dried hops.

Mechanically assisted hop stringing

What has been the response by agricultural engineers and growers to these problems? Only mechanically aided hop stringing has received no attention from within this country, but in USA and Czechoslovakia development has taken place. The Czech machinery would not fit easily into English conditions since Czech wire-work is 1 m to 2 m higher than in this country, also Czechs use 1 mm dia. soft iron wire, not string.

The American machine comprises a self-propelled elevated platform and a mechanism to make and insert in soil beside the plant a small anchor. This is sheared off and pressed from coiled steel strip several mm wide. Coir string from a spool is attached to the anchor before this is forced into the loamy soil. About 6 m of string is cut from the spool to reach the top wires where it is mechanically placed but released as it is tied to the wire by an operator standing on the platform. When observed nearly two years ago the speed of work was low and the number of operators was reckoned to be high.

The American wire-work is 5.5 m high compared with 4.9 m for much English wire-work. Also coir string is almost universally used in this country too. Soil compaction close to the hop roots differs greatly in the U.S. from that of the English garden or yard when non-cultivation allows the soil to be undisturbed for years, unlike hop ground in Washington State where soil is kept open textured for mechanical weed control and rill irrigation. With the American traditional stringing technique the strings are left hanging from the top wires until field workers dib the lower end into soil beside the roots. In windy weather the strings become entangled but development of the new machine should overcome this problem.

Mobile picking machines

Development of mechanical picking systems began in the US in the 1890's. Mobile prototypes were in use in the 1930's and one tried in UK in 1937 but found unsuitable for our conditions. Without doubt a few American mobile machines were used there with considerable success. Particularly in the Yakima Valley, Washington State, where hops are grown on precisely levelled soil (for irrigation) and this assisted their performance.

In the early 1970's another attempt was made to produce a viable mobile picker when a batch of eight machines were produced. Five or six of these are still in use, albeit with improved hydraulic

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circuits. Called the Yakima hop combine these machines and two row and cut the bines bottom and top from the wire-work. The bines are held in the vertical plane by gripping the lower ends between clamping chains which move rearwards at ground speed as the bine is rapidly combed upwards by wire loops attached to horizontal battens fastened at each end to conveyor chains. The picking rate is high and no attempt is made to clean hops from leaves and stems at this stage. This material, collected on conveyor belts low in the machine, is rapidly passed rearwards to elevators, one each side of the machine, delivering it into a trailed wagon. When filled, the wagon is detached and propels itself to the farmstead where the contents are self-unloaded into a cleaning system before the hops are dried. The performance of these machines was said to be good provided a high standard of maintenance was ensured. This meant that a competent engineer had to be in constant attendance. This was explained as a principal reason for the small number of mobile machines in use. In 1979 a less massively constructed, more simply engineered prototype was under trials in Yakima Valley, which it appeared, might well satisfy a larger market.

Work on a mobile picker continues in Germany. A very large and heavy machine was demonstrated in 1978 that was somewhat caustically reviewed by some prominent local hop growers. The hydraulically propelled and automatically levelled machine seemed poorly suited to the requirements of Bavarian hop growers who are still noted for the small size of their holdings. The makers promised continued development.

In Kent a grower of medium acreage has pioneered a simplified picking system and since has built this into a mobile machine complete with cleaning system. The Mk I machine was demonstrated publicly last autumn and offered for £70,000. Fears have been expressed of excessive damage to the cones during picking but these could be allayed if tests by an independent body were made, as urged by the designer.

Bine harvesting and transport

A long standing problem for the mobile picking machines has been maintaining mobility in wet conditions. At least two prototype mobile machines were tried in England between 1945 and 1960. One of the prime objections to their continued use was inability to negotiate wet cultivated soil between the crop rows. It can be argued, with some strength, that now nearly all gardens are under non-cultivation regimes the firmer going would make a crucial difference, but still a grower is entitled to query his position in an excessively wet summer if his harvest were entirely dependent on the mobility of his newly acquired monster.

Another powerful argument turns a substantial number of growers away from mobile pickers; it is that they already own a static machine which performs very adequately if properly serviced and set. The majority of them are 20 to 30 years old and robustly built. The replacement of worn parts is well within the capability of farm mechanics as many of them have proved.

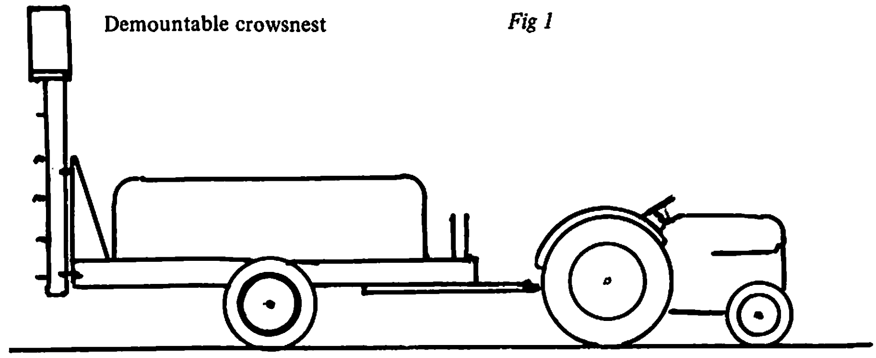


Fig 1

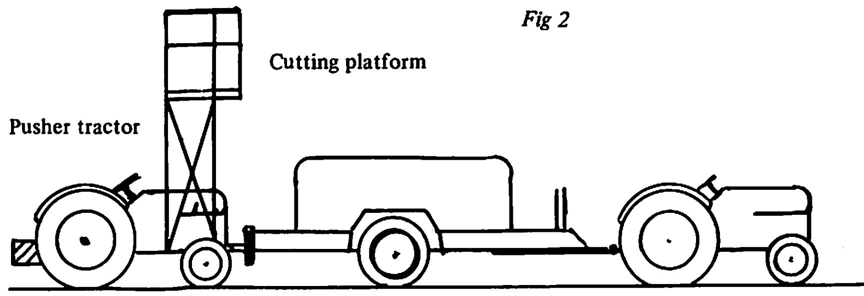


Fig 2

It is not very surprising that there was nearly twice as much interest expressed in the survey for improving bine cutting and handling as for any other aspect of mechanised hop production.

The present labour intensive system requires simple equipment. Each system requires manual cutting of bines at about chest height but a minority then pull the bines from the top wires breaking the training string, and hand load the bines on to light two-wheel tractor-drawn trailers. On the majority of holdings bines are cut from the wire-work by operators standing in 'crowsnests' temporarily secured to the rear of more substantial trailers whereby the bines fall into them in a fairly even manner (fig 1). One or two men standing at the front of the trailer pack the bines in an orderly progression to assist the subsequent regular transfer of bines on to the bine track of the picking machine.

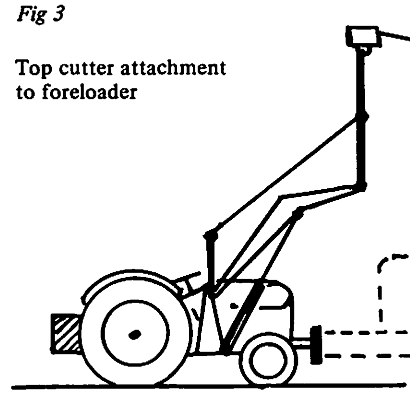
Increasingly, cutting from the wire-work is carried out from a high platform attached to the front of a tractor which also pushes another tractor and trailer. The bines are cut to fall on to the trailer in the manner described above. With this scheme two men can cut rapidly while the pusher tractor driver is well positioned to observe and control the cutting rate. No delay occurs when the trailer is full since it is towed away with minimal interference with the cutting operation (fig 2).

Two tractor-mounted imported machines which bring more mechanical assistance to bine gathering have recently been demonstrated. They gather bines from one crop wire at a time. The Belgian equipment comprises a side-mounted chest-high cutting disc, hydraulically driven, to sever the bine base, and also, projecting behind the tractor, an inclined boom terminating in a crowsnest in which stands a man cutting away the crop from the wire-work. Bines fall on to a trailer behind the tractor. The tractor driver is required to successively steer, guide the articulated cutting disc (lateral motion only) and observe the cutting rate of the man aloft. The machine is priced at £1640.

The German machine, at £4000, dispenses with the elevated worker and pulls the hops from the wire-work. Briefly, the mechanically cut bine base is firmly gripped by conveyors and positioned above and centrally behind the progressing tractor. The bine, still attached to the wire-work, is tautened as the tractor proceeds until the training string breaks and the bine falls into a trailer. The bine butt is subsequently also released into the trailer. It is hoped that both these machines will be given extended trials and modified as necessary to suit English conditions.

A third, well tried system is used mainly in Oregon, USA. There hops are cut at the base by hand but cut from two top wires simultaneously by circular knives built on top of a vertical frame in turn attached to a robust fore-loader frame. This attachment includes a parallel linkage to maintain verticality The tractor and 'top cutting' equipment are used as described above (fig 2 and 3). Thus, this is another pushing and cutting tractor, trailer and tractor configuration with three men able to cut and load 50 bines per minute consistently. This is two and a half times faster than the bines are fed into the picking machine in UK conditions.

Fig 3



Picking and drying the crop are closely inter-related processes since the storage time for picked hops before drying must be minimised to avoid crop discolouration, and must not exceed ten hours under natural ventilation at night. Having matched picking machine output capability to daily drying capacity it is important to ensure that the loading rate of bines into the picking machine can be maintained close to the maximum. Many growers fail to achieve this. Careful organisation is needed to ensure that as each trailer full of bines has been hung on the picking machine bine track that a fresh load has arrived to continue the operation. It will be appreciated that the persons transferring bines from trailer to bine track must maintain the pace of a most monotonous job, or reduce the efficiency of the whole chain of processes. No one has yet produced machinery to cut bines from the wire-work and transport them in such a manner that they can be mechanically attached to the bine track. This should reduce the size of the field gangs, mostly casual workers, by a factor of 3 or 4 as well as, increasing picking machine efficiency.

The three unreviewed topics would in themselves provide ample substance for another paper. Sufficient here to conclude with a few. words to illustrate the problem areas of each topic.

Improved crop protection by spraying

Improvement is mainly required in years of particularly vigorous growth coincident with late attack by pests and diseases. Penetration among the topmost foliage by the spray material becomes inadequate in these conditions when projected by air blast from a distance of 3.5 to 4 m. The necessity to use 'contact' pesticides just prior to harvest is likely to continue indefinitely as aphids or fungi continue to develop resistance to systemic pesticides.

Mechanical handling of picked green and dried hops

Three particular features of traditional handling methods prompt efforts to institute mechanical handling systems. Firstly dis-satisfaction with handling the crop in 'green sacks' of some 20 kg. Secondly, drying time and some fuel can be saved where mechanical loading has ensured even density of hops on the drying floor. American experience points to the truth of this. Thirdly, as more growers change to packing dry hops into bales instead of 'pockets' bulk movements of hops becomes more economic. A two-shot bale press allows the quick movement of almost 1.5 m^3 of loose hops at each charge of the press.

Improvements in hop drying

The three fold relative increase cost of drying fuel has concentrated many minds on increasing drying efficiency. Broadly two approaches are being considered. Most widely, means are sought to reduce the fuel consumption of existing kilns (which varies greatly kiln to kiln). Plans to ensure optimisation of bed depth, air speed and temperature regime are needed, while re-circulation of partially saturated exhaust drying air could bring substantial economies.

Secondly, those few growers who year by year have to plan new kilns have the opportunity to make radical changes. Should they plan three tier kilns or buy continuous driers? The answer depends on fuel saving but also on the availability of labour and capital. The short harvest period, 20-25 working days, makes high capital expenditure a difficult decision.

Mechanical harvesting of soft fruit

Edward Day

Introduction

BY the very nature of the crops, the mechanisation of soft fruit harvesting has been comparatively slow to develop. The response of the grower to mechanisation has followed the same logical pattern that I can well remember with hop picking in the 1950's. Until the grower has a very real need of mechanisation due to shortage and/or cost of available hand labour, he will find much fault with the first prototype efforts of the manufacturers. As his need becomes greater it is quite surprising how readily he will come to accept previously unacceptable shortcomings in early design and start to buy, which in turn finances greater research efforts by the manufacturer.

As my experience in soft fruit harvesting has been confined mainly to the bush fruits, and as the harvesting of these is very advanced it is perhaps logical to take them first.

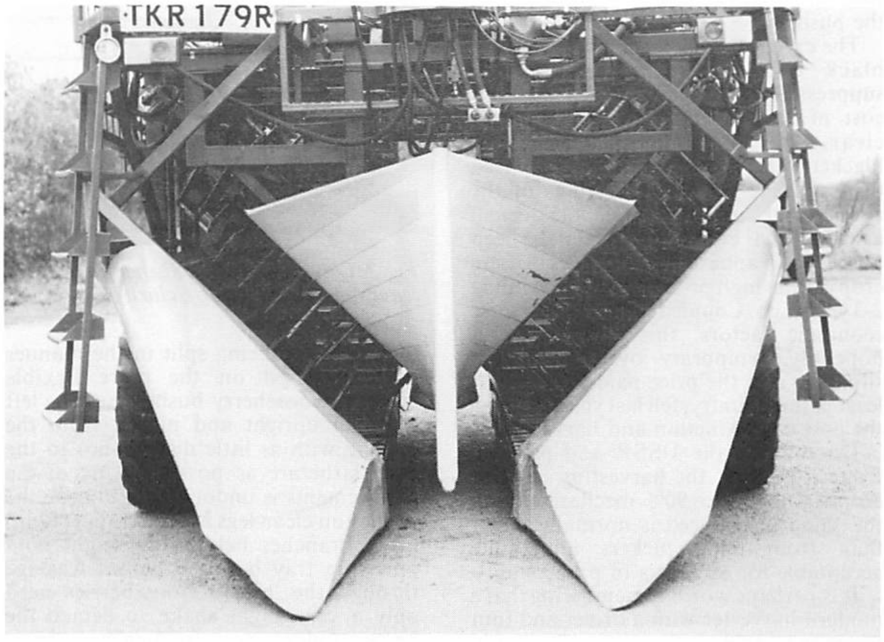


Fig 1 Original design of blackcurrant harvester

Black and red currants

The first complete harvesting machines were of the 'destructive' type. All the branches were cut at ground level and conveyed to the headland on canvas sheets to be picked and cleaned on a static unit. This employed wire loop fingers to remove the berries similar to those developed at that time for hop picking machines. Such 'destructive' harvesting had the obvious drawback that the bushes could only be cropped in alternate years resulting in, not only a significant loss of crop, but an increase in mildew. It was clear that some form of 'non destructive' harvesting would have to be developed whereby the bush would be left substantially undisturbed before mechanical harvesting of these crops would be widely accepted.

It was 1970 before the first such machine was seen in the field (see Fig. 1). The principle of an over the row harvester parting the row and with drums of vibrating figures to remove the fruit remains to this day the predominant design. Research stations in the early 70's conducted trials to establish the extent to which the removal of leaves and inevitable minor damage to the soft wood of the bush would affect the crop in the following year. Leaf removal at the levels being experienced by the vibrating tine machines was found not to be a significant factor. There is, however, some minor damage by the small diameter tines striking the soft wood. In Finland they have found that there is so little summer remaining after harvest that abrasions have insufficient time to heal and disease enters and winters in the wounds causing a significant reduction of crop the following year.

We have undertaken a worldwide programme to re-educate growers in the planting and pruning techniques most suitable for machine harvesting. It was apparent that traditional practises would have to be modified fundamentally to ensure that the branches would be grown at right angles to the line of the row thus being presented to the picking drums at the optimum angle. Those which grow up the line of the row are not picked at all. This requirement has led, not only to simple pruning recommendations but also to closer planting of 60-75 cm in 3 metre rows, instead of the traditional 3-4 metres square. The continuous hedge thus formed encourages branches to grow in the right direction.

The characteristics of the vibration have been the subject of much research and experimentation. If a tine tip amplitude is applied greater than the normal strig length, then the weight of each berry is used to assist in its own detachment. This technique has made possible a significant reduction in frequency and hence bush damage, since the branches are struck every time the tines change direction. The shape of the shaker weights has also been modified to induce a flick action at the reversal point which further facilitates fruit removal.

The early fruit recovery conveyors incorporated a space between them to allow bush passage. More recently a much more efficient and sophisticated catching conveyor system has been developed comprising a series of 10 cm (4 in) wide trays mounted on side chains on each side of the row. The conveyors, which have a common drive, are accurately timed to move rearwards at precisely the same speed as the machine moves forwards. This speed match is accomplished by a land wheel which rolls along the ground at the side of the machine sensing the achieved forward movement. By means of a differential gear and valve system the conveyor speed is accurately matched at any time to the forward speed of the machine. The trays, which are spring loaded towards the centreline thus have a zero speed relationship with the bush and individual trays either rest against the bush, or in the absence of a bush extend to the centreline, thus forming a catching carpet around and in between the bushes. This conveyor forms the basis of our present generation machines (fig 2 and 3).

More recently we have given high priority to the problem of picking really young bushes. The life of a blackcurrant bush is about 15 years and for the first 2-3 cropping years (depending on conditions), it is a 'small' bush standing 75 cm (2 ft 6 in) high with crop down to 15 cms (6 in) above the ground. At this height, the present generation of

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machines have some difficulty, not only in picking the fruit but more especially in its recovery, and high wastage levels are experienced.

In 1980 we set out to design a machine specifically to pick these small bushes since it was apparent that they represent some 15-20% of the total acreage. The prototype has been very successful and we are now investigating ways in which the bush handling, fruit removal and catching principles involved may be applied to the larger machines to make them more efficient over the whole life of the bush.

The extent to which the production of black and red currants has been suppressed in the past by shortage and cost of hand labour has now become clear. Not only have traditional blackcurrant growers rapidly increased their acreage but other sections of the agricultural industry such as cereal growers and even New Zealand sheep farmers saw apparent advantages in these crops at the high prices of fruit prevailing 2-3 years ago. Coupled with other adverse economic factors, this has caused a, hopefully, temporary over production situation and the price paid for fruit, at least in this country, fell last year to below the cost of production and harvesting.

Discounting the USSR and parts of Eastern Europe, the harvesting of these crops is now over 90% mechanised and the sample produced is normally better than from hand pickers and quite acceptable for all forms of processing.

It is perhaps worth remembering that a modern harvester with a driver and four operators replaces some 500 hand pickers.

Gooseberries

This minority crop at the present prices paid for the fruit, will not support the development of a special purpose machine.

The wood of the gooseberry is much more brittle than that of the currant and the bushes do not therefore lend themselves to being split in the manner normally used on the more flexible currant. Gooseberry bushes must be left standing upright and picked from the outside with as little disturbance to the bush structure as possible. One of the requirements is undoubtedly to have the bushes on clean legs at least 30 cm (12 in) high. Branches below this height hold open the tray bed and permit wastage through the 'holes'. Gooseberries need only a very slight shake to detach the berries, indeed excess frequency increases the tendency for the fruit to fly around inside the machine and out of the front and rear.

Because this crop is of low value and will not pay for the comparatively high cost of hand pickers successful adaption of a blackcurrant harvester is a high priority for gooseberry growers. It is fortuitous that the harvesting period is consecutive to that of blackcurrants making this a potentially viable solution.

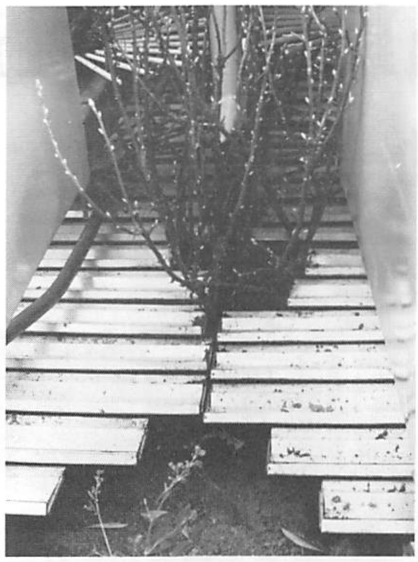
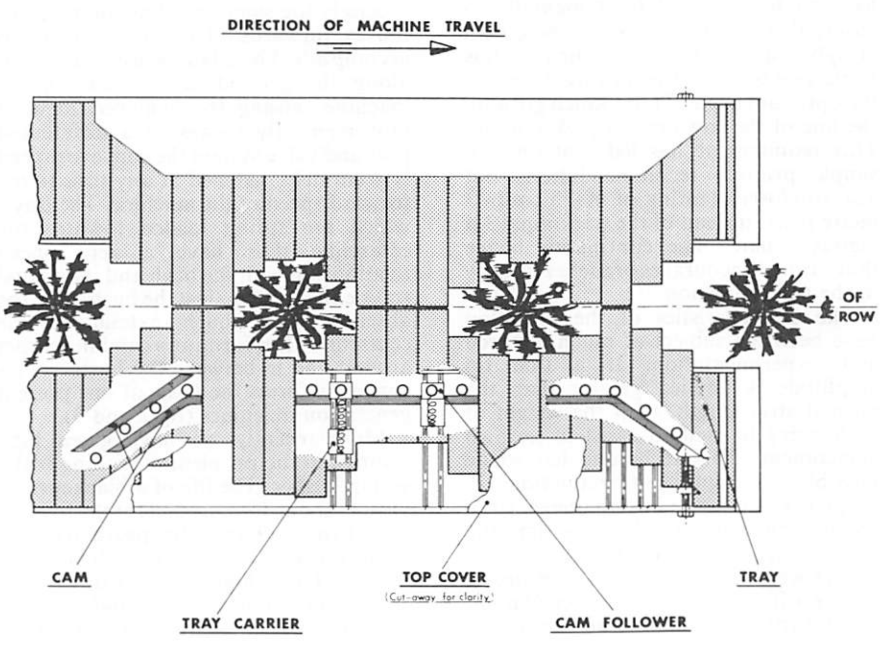


Fig 2 Trays wrap around the bushes; the leaves are removed for clarity

Fig 3 Cutaway showing cam and tray carrier operation



Raspberries

The development of mechanical harvesting of soft fruits has naturally taken the line of least resistance. The bush fruits have been the easiest to conquer and now we move into one of the two really difficult areas. The problems of raspberry harvesting fall under four main headings:—

1. Removal of fruit from the cane
2. Damage to the berries
3. Damage to canes by the collection means
4. Losses through the catching device.

The solution of these problems is by no means a *fait accompli* as it is in the USA and an acceptable commercial harvester has yet to be seen in Europe. The role of the breeder in developing varieties suitable for machine harvesting is more important in this crop than in any other soft fruit.

Removal of fruit from the cane

Unlike the bush fruits raspberries must be removed from the cane leaving the stalk and plug behind.

Two main methods of fruit removal have been tried. Vertical drums of tine rings vibrating in the fore and aft plane as used on the blackcurrant harvesters and beaters agitating the row from side to side as used on the grape harvesters. The latter appears to be more efficient and one theory is that the fruit is under the influence of the agitation for longer and the berry is 'worried' off its plug over a relatively long period of time. The flick action of the former method tends to remove more unripe berries.

All the ripe fruit should be completely removed but this is not always achieved and some berries only partially detached hang on to the plant in a damaged and later diseased condition causing problems in the sample the next time around. The selection of new varieties with a firm texture will also assist in a solution to this problem in that such firm berries are also less prone to rot.

Damage to the berries

Mechanical harvesting of black raspberries in the USA has been used with success since 1960, and of red raspberries since 1966. The American black raspberry is very much firmer than the European red and will tolerate mechanical handling to a degree unheard of this side of the Atlantic. Partly due to the high humidity climate in which it is grown, the traditional Scottish red raspberry, is very soft. Even quite gentle handling by hand pickers can rupture the individual 'droplets' causing the berry to bleed to the deterioration of the sample.

Damage to the young cane (spawn)

Early harvesters used spring loaded metal 'fish plates' for catching the fruit. Under Scottish conditions, however, these have proved to be unacceptable in that they scrape along the spawn making abrasions into which fungal infection enters. This in turn causes cane blight resulting in significant reduction of next year's crop.

We have carried out experiments at Marden using our blackcurrant catching conveyor with its zero speed relationship to the plant and although slight abrasions were apparent, ADAS tests did not show that the incidence of Cane Blight was a problem of commercial significance.

The Scottish Institute of Agricultural Engineering has developed a type of timed conveyor similar in some respects to the blackcurrant conveyor, in that a continuous rubber 'band' is held at a zero speed relationship against the row and this acts as a soft continuous catching seal almost eliminating the damage to the spawn associated with fish plates.

Losses through the catching device

The presence of so much vigorous spawn growing up through the fruiting cane, makes it difficult for the detached fruit to fall free on to the catching and conveying mechanism. Many different cultural techniques have been tried to overcome this problem, mainly on the principle of separating the fruiting cane from the spawn at time of harvest.

Perhaps the best known method is that developed by Lincoln College, nr Christchurch, New Zealand, whereby the fruiting cane is lowered to the horizontal for picking, allowing the spawn to grow up through the middle.

The obvious apparent advantage is that a simple conveyor can be positioned underneath the cane without actually making contact with it at all. There are few ground losses with this method, but the effectiveness of the horizontal drums of vibrating fingers leaves much to be desired. A further disadvantage is that such a system is wasteful of land in that the distance between the rows has to be of the order of 4.4 metres (14 ft) to permit the passage of the harvester, rather than the more usual 1.8 metres (6 ft) found in Scotland. The slight increase in crop per unit length of row does not compensate for this considerable reduction in fruiting cane per acre.

More recently promising experiments have been conducted to assess the merits of biennial cropping to overcome this difficulty (Waister and Cormack 1976). Under this system alternate rows are cut down each year to ground level. Clearly there will be a yield penalty but work by the Scottish Horticultural Research Institute has shown that it is not necessarily an economic one since there is a very significant increase in yield per unit length of row, thus making harvesting cheaper. There may also be an improvement in the amount of fruit recovered by the catching means in the absence of the young spawn. Although promising results have been obtained on some traditional varieties, I understand that no positive recommendations are yet forthcoming for the newer machine harvesting varieties.

This technique has a number of advantages not least of which is the possible removal of the requirement for posts and wire, and thus the possibility eventually to mechanise the whole growing and harvesting operation.

To summarise:—

We have in the UK probably the most active breeding programme in Europe aimed at producing varieties commercially suitable for mechanical harvesting. The main effort is being directed at marrying the firm characteristics of the American black raspberry with prolific and potentially disease resistant strains. In the meantime machine picked samples, though not up to retail pack standards, are certainly fit for jam manufacture. Up to 50% of mechanically harvested fruit from such cultivars as Glen Isla may be used for IQF when the machines are further developed.

The mechanical harvesting of raspberries for the fresh market is still in the distant future whilst the markets are as they are and unemployment remains high.

Strawberries

I must confess that I have not yet had the opportunity of seeing a strawberry harvester at work and the limited information that follows must therefore be taken as an effort to complete the picture on soft fruit harvesting, rather than as an authoritative treatise on the subject.

The once over harvesting operation falls into two main phases:—

The cutting, cleaning and singulating phase

The harvester unit in the field is typically self-propelled. The whole of the growth of the plant comprising fruit, leaves and stems is mown off with a reciprocating cutter bar at about 10-12 cm (4-5 in) above the ground. Various methods are used to lift and comb the mass of foilage so that a clean cut and efficient collection can result. These include various designs of lifting fingers, mechanical combs and/or air blast. It is clearly important that the ground is carefully prepared into a flat topped ridge 50-60 cm (20-24 in) wide to ensure that all the plants are at the same level. The performance of the cutting and recovery mechanism is further enhanced in conditions of a continuous, dense and upright stand of plants. Wastage is greater where there are spaces in the rows, and when the plants hang over the sides of the ridges. Many of the early experiments in this country have been on traditional plantations and this has undoubtedly caused some lack of success in this part of the operation.

The mass of foliage and fruit is then broken up into its constituent parts. Leaves and trash are blown out at an early stage and bunches are separated.

The capping phase

This is normally carried out at the farm. The remainder of the trash is separated and the berries are then gripped by their stalks typically by counter-rotating rollers and a band knife slices off the calyces. The distances of the knife from the rollers must be carefully adjusted to suit the variety. Those with a deeply recessed calyx cavity are wasteful since the cut must be made well into the berry to ensure that all the calyx is removed.

As in the case with the other fruits there is much that the grower can do in the preparation of his fields for the harvester and by the breeder in developing strains which have such properties as more even ripening and a slight neck to facilitate efficient removal of the calyx. It seems likely that for the forseeable future the product of strawberry harvesters will be of a quality suitable only for the process market and it may therefore be economical, if labour is available, to take the first picks for the fresh market by hand, and use the machine to clear up the crop for processing.

The process customers regrettably may not yet be fully prepared in this country to accept a machine picked sample when abundant supplies of higher quality, and perhaps lower priced, fruit can be obtained from other sources.

The shortage in some areas and the universally high cost of hand pickers have recently added new impetus to the development of mechanical harvesters for soft fruit. The immediate future for raspberries and strawberries is a continued expansion of pick your own for the quality fruit whilst harvesters will be further developed to supply an increasingly better quality sample for the process market.

Reference

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Mechanical harvesting of top fruit

M J LeFlufy

Introduction

ALTHOUGH techniques of mechanical harvesting top fruit have been under development for a number of years, there is at present no commercially available machine which is capable of harvesting good quality fruit for the fresh market. A number of intriguing machines have however been developed and some have found a market for use with fruit intended for processing.

The harvesting operation can be broken down into three stages: detachment, collection and transport.

Since the top fruit grown most widely in the United Kingdom is the apple, the techniques and machines described in this paper are concerned primarily with apple harvesting.

Detachment

As fruit ripens ethylene is produced at the abscission layer between the fruit stalk and the fruit-bearing spur, weakening the bond at this point. This bond is eventually so weakened that the fruit drops under the action of wind and gravity. By this time, however, it is normally over-ripe for the dessert market.

The mechanics of detachment have been extensively studied (Singley, Moore and Childers 1962: Parchomchuk and Cooke 1971) and it has been found that the abscission layer separates most easily under the "peeling" action induced by bending. Not surprisingly, this is the technique used in manual harvesting where the fruit is lifted and twisted. This action is extremely difficult to simulate by machine unless it can identify and remove each fruit individually, which at present is clearly an uneconomic procedure.

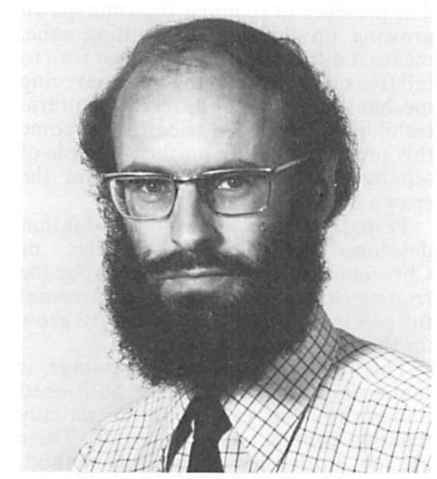
Shaking

The most widely used method of detachment is some form of tree or limb shaking (Berlage 1976, Millier 1978). The "peeling" action may be obtained by inducing the stem to buckle, but detachment is most likely to result from repeated oscillations of the fruit which finally leaves the limb travelling almost horizontally. Successful detachment of downward hanging fruits may also be obtained by applying a sharp upward acceleration to the limb. The abscission layer is broken by the resulting high tensile loading in this case.

Tree trunk shakers have now been developed into efficient units for trees with a stiff branch framework, using either a rotating eccentric weight multi-directional unit or a hydraulic bi-directional impulse unit. Fruits are however often damaged by violent oscillation which occurs before detachment and also by contact with branches after detachment. Where the fruit is resistant to damage or where damage is of minor consequence, such as in the harvesting of sour cherries or cider apples, the shaking principle has been successfully incorporated into production harvesters.

A number of attempts have been made to modify the shaking action to minimize fruit damage. The hydraulic impact units are designed to remove the fruit using only three or four individual sharp impacts, so reducing fruit movement. In practice fruit velocity remains high and any reduction in damage is minimal. More success has been obtained using individual limb shakers where the violence of the shake can be significantly reduced. Shaking each major limb of an extensive tree is, however, awkward and time consuming. This method has been used experimentally on the *Tatura trellis* in Australia (Chalmers, van de Ende, van Heek 1978).

A potentially more effective impact device is currently being developed in New Zealand for use with apples grown on a horizontal canopy (J S Dunn, 1976 *et seq*). Here, the fruit generally hangs vertically beneath a horizontal branch framework. A sharp upward impact on the underside of the canopy effectively lifts the canopy away from the fruit, leaving the fruit stationary at the moment of detachment and free to fall thereafter. Where the fruits are not all hanging below the canopy, as is often the situation with "Cox's Orange Pippin" grown under British conditions, detachment is more difficult and fruit may be projected upwards as a result of the impact. The abscission layer bond may also be weakened by spraying with a chemical to induce the production of ethylene, which reduces the intensity of shaking required for detachment. Although sometimes erratic in operation, such chemicals are used in the harvesting of sour cherries.



Combing

A completely different approach has been

Fig 1 Mechanical harvesting of top fruit

M J LeFlufy MA, Research Officer, National College of Agricultural Engineering, Silsoe.

adopted in investigations at the National College of Agricultural Engineering at Silsoe (fig 1). In an attempt to simulate more closely the action of the human hand it was decided to comb the fruit upwards from the branches. This principle has been tested on hedgerow apple trees grown specifically for mechanical harvesting at Long Ashton Research Station near Bristol and is very effective in removing short stemmed fruits such as the "Cox" cultivar where the action of lifting the fruit is sufficient to break the abscission layer by bending. With long stemmed cultivars such as "Golden Delicious", this does not always occur and detachment may be due to a tensile failure of the abscission layer as the fruit is lifted upwards. This combing method depends on the branches being slender and flexible so that they pass easily between the stiff combing fingers. It is thus limited to cultivars grown as hedgerows (Child and LeFlufy 1979).

Collection

Single level catching surfaces

Collection after shaking presents two major problems. Each fruit must be brought to rest without excessive deceleration and then it must be removed before any further fruit is caught in the same place in order to prevent fruit-on-fruit impact damage. The first problem may be readily solved by using a thickly padded surface with decelerating strips of rubber or plastic sheet, which also help to contain any rebound, suspended above it. However, when a large number of fruits are falling simultaneously on to a restricted area, as happens during tree shaking, it becomes difficult to prevent the fruit-on-fruit impact damage. The best solution appears to be to bring the fruit velocity virtually to zero on overlapping decelerator strips which then allow the fruit to roll or fall gently on to a padded conveyor below, where fruit-on-fruit impacts do not cause damage. A number of commercial processing fruit harvesters use such a system and it has been used on experimental fresh fruit harvesters (Clark 1971, Zocca 1977).

Other methods of collecting freely falling fruits include the use of a deep bed of granules which "absorbs" each fruit and closes back over it and the use of a deeply quilted surface which partly absorbs the fruit (Pellerin 1978). The latter method allows the fruits to be separated easily from the catching medium, which is difficult with the loose granules, but does not entirely prevent fruit-on-fruit damage. Cider apples are generally shaken directly on to the ground.

Multi-level collection

Early harvesters used a single catching frame positioned at the bottom of the tree. However effective the catching surface, considerable damage is done to the fruits before they ever reach the base of the treee. Various experimental machines have been designed to collect the fruits while they are still within the tree framework. This entails inserting a catching surface into the branches, an operation which presents considerable difficulties. Some trials were undertaken with inflatable fingers which could be inserted into the branches and then inflated to create a soft corrugated catching surface (Millier 1978). An overrow apple harvester developed at IMAG at Wageningen, Holland for use on small spindle trees was fitted with trough shaped fingers which were inserted into the trees at the front of the vehicle and withdrawn at the rear on a continuous conveyor system. The trees were pruned to produce three or four layers of branches with sufficient space between the layers to allow for the insertion of the catching fingers (van de Werken 1978). These multi-level collection systems tend to decrease the efficiency of fruit removal by shaking since they damp out branch movement, but the main objection to any system of shake-and-catch harvesting is that virtually all top fruit is damaged by a fall of only a few centimetres on to a hard surface.

Single layer canopies

The only possibility therefore of successful shake-and-catch harvesting of fresh market fruit is to ensure that the fruits develop under the branch canopy so that a catching surface can be positioned immediately below the fruit.

The New Zealand horizontal canopy (see section on Shaking) is being developed to achieve just this. The problems arise more with tree training and delayed first cropping than with the actual harvesting operation.

The Tatura trellis mentioned in the section on Shaking involves training the trees on a vee shaped trellis so that the fruit hangs below the tree framework. A multi-level catching frame can therefore be easily positioned under the trellis and the fruits fall directly on to the catching surfaces. Tree control is claimed to be simpler than on a horizontal canopy but the harvesting operation is less straightforward.

Combing

The combing method of harvesting eliminates the problem of catching free falling fruit by using the combing fingers as both the removal and collection devices. By angling the fingers downwards out of the hedgerow the detached apples merely roll out of the tree framework and on to a conveyor either side of the harvester. Since the fruit velocity is low at all times there is very little damage. Any damage which does occur is generally caused by fruit being pressed upwards into branches or against other fruit during detachment. There are three main drawbacks to this system. Firstly 10 to 15% of fruits which grow close to the central trunk are not removed. Secondly a further percentage are detached but subsequently slip through the fingers and thirdly damage can occur to branches and new fruit buds. The last two problems are inter-related since more tree damage is caused by those fingers which are the most effective in retaining the detached fruit.

Transport

Container handling

Although successful detachment and collection remain the major obstacles to the mechanical harvesting of top fruit, transportation also requires careful development and planning. Having been brought to rest on a catching surface the fruit must then be moved out of the orchard. Since the catching surface forms part of a conveyor system, it would be possible to envisage long conveyors carrying the fruit directly out of the orchard. However a more practical method is to load the fruit into containers which may then be handled by conventional machinery.

Difficulties arise in the positioning of these containers in the orchard. Harvesting machines are generally large and capable of filling a number of containers very rapidly. There must therefore be a system of supplying them with empty containers and removing full ones which is capable of operating at the same rate as the harvester unless there is sufficient clear space in the orchard for containers to be deposited at will, without hindering the progress of the harvester.

Probably the most practicable arrangement is to design the harvester to carry sufficient containers to enable it to collect empty ones at each headland and deposit them in the orchard as they become full, for collection later. The bulk and weight of most top fruit makes the harvester very cumbersome if it is to be capable of storing full containers as well as empty.

Container filling

Provided that care is taken to prevent fruit contacting hard surfaces or sharp edges, the transport of the fruit from the collection surfaces to the bulk container is relatively straightforward. More care is needed in actually filling the container. It is often necessary to have a system which automatically controls the height of the loading conveyor above the level of the fruit already loaded either by raising the conveyor or by lowering the container. Commercial loaders are available and are used successfully on the Continent in conjunction with mobile picking platforms.

Cider apples

Transport of cider apples generally involves the extra stage of lifting them from the ground. Several machines have been developed and this is now accomplished efficiently, albeit with a possibly detrimental level of damage, using a reel of rubber flaps rotating so that the apples are thrown forwards and upwards against a rubber skirt before being carried back over the top of the reel and thrown out on to a cleaning and conveying surface. The major current problem lies in the determination of the optimum size of harvester and its method of propulsion. The smaller pedestrian controlled self-propelled harvesters are very effective but require considerable time and energy to be spent in transferring the fruit from their small containers (baskets or bags) to bulk containers (typically a 3 tonne open trailer). The larger harvesters are now tractor mounted and fill a trailer directly. The extended tractor/trailer combination can be awkward to manoeuvre in some orchards and the fruit needs to be windrowed in most cases before being picked up. A self-propelled harvester with an integral carrying capacity of about ½ tonne has been produced but became too costly to be economic.

The future

Where fruit damage is of minor consequence, whole tree shaking is a very effective method of fruit removal. However, the majority of top fruit is required to be in good condition after harvesting. There are probably only two ways forward to good quality mechanically harvested top fruit and both involve considerable changes to the accepted methods of training trees.

If shake-and-catch is to be used it must be with trees trained on to a well defined thin horizontal canopy, which implies wire supports. An impulse shaking system which induces fruit detachment with the minimum of fruit movement would need to be developed. A small harvester which ran beneath the canopy could then be produced using a padded conveyor to catch the fruits after a drop of only a few centimetres. A system of handling and loading suitable bulk containers could also be designed.

The pomological problems appear to be eased if the fruit is grown in hedgerows. On this system the combing principle would have to be used. Although showing promise, further development is required to minimise the damage to the trees while retaining an adequate level of fruit removal and collection.

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The application of micro-processors to controlled atmosphere fruit storage

David J Bishop

Introduction

IT has been shown (Sharples *et al* 1978) that apples can be stored with advantage in ultra low oxygen conditions. In order for this to be carried out reliably over a long time, automatic control of the storage environment is considered to be essential.

Automatic measurement and control of conventional controlled atmosphere stores can also be of considerable benefit to the grower in that it reduces manpower requirements, improves the atmosphere control and provides unambiguous recording of all the store parameters.

David Bishop Instruments Ltd have designed, manufactured and installed two micro-processor based automatic control and measuring systems which have been installed in commercial fruit stores for use during the season commencing September, 1980. One of these installations was for four x 120 tonne stores and the other was for twelve x 100 tonne stores. They have been used successfully this season for the storage of a variety of apples under various oxygen regimes. Table 1 shows various typical conditions for controlled atmosphere storage (Sharples and Stow, 1978).

Table 1 Typical fruit storage conditions

Variety	*Terminate*	*Temp ^oC*	*$\%O_2$*	*$\%CO_2$*
Cox	March	3.5 to 4	2	<1
Cox*	May	3.5 to 4	1.3	1
Worcester	March	0.5 to 1	3	5
Bramley	May	3.7 to 4.5	–	8–10
Conference	April	–1 to –0.5	2	1

**Not yet recommended by EMRS for general use.*

Measurements

The usefulness of any automatic control and recording system is dependent on the quality and reliability of the measurements made of the variable parameters. It is therefore essential to correctly select and properly install the instruments necessary to provide automatic measurement of oxygen, carbon dioxide and temperature.

Oxygen

There are various methods available for the automatic measurement of oxygen (Tipping 1974). It has been found from experience that the magno-dynamic type of cell which measures the paramagnetic susceptibility of gaseous oxygen (Munday 1957) provides a rugged, accurate and reliable measurement over the range of interest. The Servomex OA540 has been used because this instrument is designed for continuous operation and has a temperature controlled housing to ensure the long term stability of the measurement.

Carbon dioxide

The traditional method of determining CO_2 by using thermal conductivity measurements does not give sufficient accuracy when low oxygen storage is used. The full accuracy, stability and cost of a ratio type infra-red absorption instrument is not however necessary, and therefore we use a simple single-beam infra-red absorption meter which gives a reasonably accurate and stable measurement of CO_2 in the range of 0-10%.

Temperature

We have found that the best way of measuring temperature with high accuracy, ruggedness, long term stability and ease of installation is a system based on precision thermistors connected to a linear network. Each probe is connected in turn by a relay to a bridge circuit which provides an output voltage directly proportional to the temperature. This is displayed on a digital meter as degrees °C as well as being connected to the computer.

Gas sampling

A diagram of the gas sampling system is shown in fig 1. The sampling point within the store must be in a position of good circulation produced by the store fan but away from the outlet of the CO_2 scrubber so that a representative gas sample is obtained. The pump and the solenoid valve are operated by the control system when programmed to do so. They operate for only one or two minutes approximately every hour and therefore the gas taken from the store is of low volume and hence discharged to atmosphere after use.

Suitable precautions have been taken in the design of the sampling system to prevent the sampling lines and solenoid valves being obstructed by dirt, insects and leaves. Care was also taken to avoid

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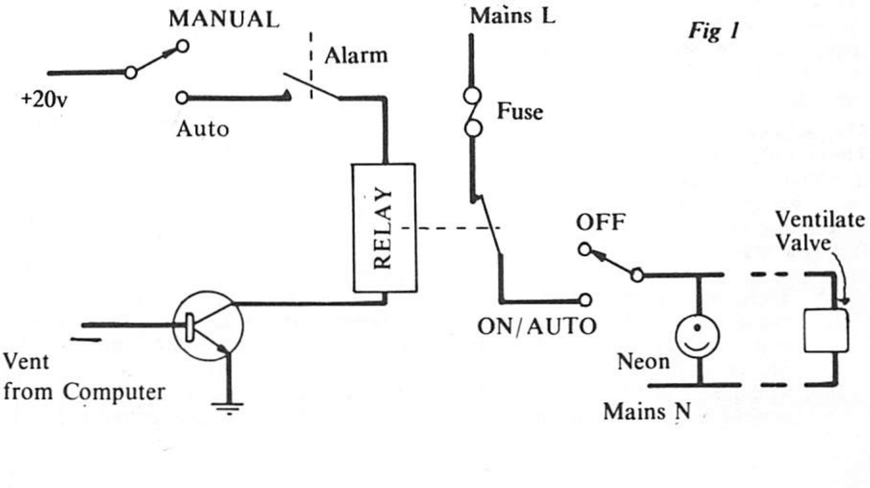

Fig 1

condensate being trapped which can cause irregular flows and blockages due to ice at low ambient temperatures.

The sampling lines were installed with the absolute minimum of connectors and the suction section of the line kept as short as possible. An additional sampling pipe was also connected to the store to enable separate readings with portable equipment to be made as a double check on the store atmosphere (Chappell 1979).

Store ventilation

In a fully sealed store it has been found that fruit will absorb oxygen up to the rate of 0.1% O_2 per hour (Chappell 1980). The volume of ventilation air can then be calculated as follows noting that atmospheric air contains 21% oxygen.

$$F = V \times .001 \times \frac{100}{21}$$

where V is the empty store volume in m^3 and F being the flow rate needed in m^3/hour. Two different methods of store ventilation were used in the installations under review.

(a) Forced Ventilation: An oil-free diaphragm pump was used to introduce air at the maximum flow rate needed directly into the store. An exhaust pipe was also fitted to prevent a pressure build up.

(b) Fan Ventilation: The system relied on the suction produced by the store's own circulation fan to pull air in through the existing fresh air pipe. A solenoid valve was fitted on this pipe to enable the control system to regulate the flow.

It is considered essential (Chappell 1979) that stores equipped with automatic atmosphere control have some form of pressure relief valve to prevent damage to the store structure in the event of equipment malfunction.

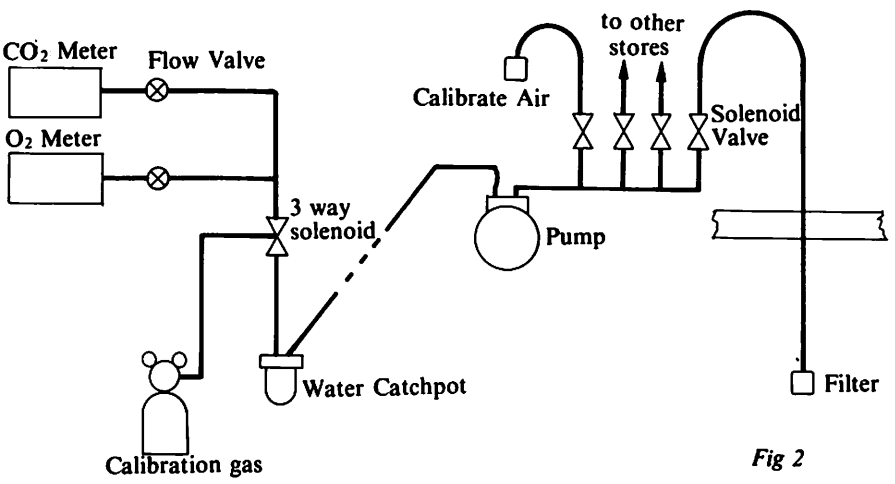

Fig 2

Table 2 Data entry – Non store data

Code	*Function*	*Units*
00	Date and Time	Month day hour min
01	No of stores	1 to 12
02	No of temp. probes	1 to 5
03	Calibrate sample time	1 to 5 mins
04	Sample delay time	1 to 5 mins
05	Wait time	01 to 99 mins
06	O_2 zero high alarm	+00.0 to 01.9% O_2
07	O_2 zero low alarm	−00.0 to −01.9% O_2
08	O_2 span (fresh air) high alarm	+21.0 to 25.9% O_2
09	O_2 span low alarm	±15.9 to +21.0% O_2
18	Print all non store data	
19	GO control cycle	
20	GO cal cycle	
22	Calibrate frequency	01 to 99 cycles

Automatic control

Many types of electronic control and recording were investigated before the micro-processor control was chosen.

For the cost of a conventional four store system recording and controlling just the oxygen level, a micro-processor system could be built with improved oxygen control as well as recording and alarming for carbon dioxide and temperature. In addition, much greater flexibility was achieved together with the possibility of extending to twelve stores at very little extra cost.

Before the detailed design was started certain guidelines were formulated to ensure the successful introduction of micro-technology to the farm environment.

Manual over-ride

The complete system was designed so that it could be operated manually. Each valve, pump and analyser had a manual switch and ON indicator driven directly from the mains. This had two important advantages:

(a) The system can be operated in the event of any electronic failure either in the computer or the power supplies.

(b) The user is first trained to use the system in the manual mode. As this is very similar to what he is used to it makes understanding the automatic system very much easier.

Fail safe operation

Many features were built in to ensure that should a failure occur the stores would start to ventilate in order to prevent alcohol damage, (North and Cockburn, 1975). The ventilation circuit shown in fig 2 is arranged so that the computer normally holds the relay energised and only de-energises when ventilation is required.

The stores will ventilate in the following circumstances:

(a) when required due to low oxygen
(b) DC failure, ie fuses, transformers, etc
(c) the computer fails to execute a test routine properly
(d) the oxygen analyser fails to read the correct value of the calibration gases
(e) no gas flow from the store being measured.

Alarm system

There are two levels of alarm. The first as described above will cause ventilation to occur. The secondary alarms are activated when the measured values exceed their preset limits or when the calibration gases are exhausted. The alarm consists of an indicator lamp and audible sirens which can be in various locations. The cause of the alarm is always printed on the printer thus guiding the operator immediately to the problem area.

Operator interface

All the program information is entered through a simple numeric keyboard. The output is normally displayed on the printer but a video display unit can be used. The printout prompts the user into entering the required information and it will not accept entries in the wrong format. All codes are held within the computer memory and they are printed out on start up and thereafter on request.

Battery back-up

A battery system maintains all the parameters entered into the memory by the user in the event of a mains failure. They can be altered at any time by entering new values through the keyboard. The keyboard is disabled by a key operated switch to prevent unauthorised operation. All operating programmes are held in 'Electrically programmable read only memories' (EPROM) which in normal circumstances retain their memory indefinitely but can with special equipment be changed as needed.

Computer functions

All the operating limits and levels are entered into the computer through the keyboard. There are two sets of instructions. One set called the 'non store data' shown in table 2 sets all the timing and calibration limits whilst the second set are shown in table 3 and can be different for each store.

When all the information is entered instructions 17 and 18 can be requested so that all the data entered can be listed out for checking and record purposes.

When code 20 is entered the system enters its normal operating mode. Space does not permit detailing every operation but the basic sequence is as follows:

(a) Introduce calibration gases to oxygen and carbon dioxide analysers and print out readings. Alarm if oxygen analyser readings are outside preset limits. Alarm if flow is not correct (ie gas bottle is empty).

(b) Measure temperature from five probes in Store 1. Alarm if the temperature of Probe 1 is outside of preset high and low limits.

(c) Switch on pump and sample solenoid valve to Store 1 and after a preset delay (code 03) measure and print oxygen and CO_2 levels. Alarm if oxygen is outside of high and low preset levels and alarm if CO_2 is above preset level.

(d) Compare the measured oxygen level of Store 1 with the required 'Set Point' level and switch on ventilation for a period of time determined by the equation: $T = A \times B$ mins
where A is a value programmed into the memory and B is determined as follows:
$B = (SP-O_2)$ 20
B is approximated by the computer to a positive whole number with a maximum value of 4. SP is the set point in $\%O_2$ and O_2 is the actual oxygen reading.

(e) Repeat stages 'b' to 'd' for all the other stores. The ventilation time in 'd' is independent of the main programme and operates simultaneously to it.

(f) When all the stores have been measured the system will wait for a preset time (code 05) before repeating the sequence.

(g) To conserve calibration gas and paper, the system can be programmed to omit calibration and printout for a preset number of cycles (code 22). All alarms continue to be printed if they occur.

Computer hardware

The computer was made by Crealec Laboratories Ltd using a standard single board micro-computer with a custom made interface board containing the A to D convertor and the output driving transistors. The computer is based on Mororola 6802 8 bit processor with 2048 x 8 bit random access memory and 6144 x 8 bit electrically programmable read only memories.

To obtain the high accuracy and resolution required an Intersil 7109 Dual Slope 12 bit analog to digital convertor was used. The output to the printer is Serial RS232C data which can be used by many common printers and VDU units. The printer used in these installations was a Teletype 43.

Table 3 Data entry 'store dependent data'

Code	*Function*	*Units*
10	Vent time	01 to 99 mins
11	Temperature high alarm	−06.0 to +25.0°C
12	Temperature low alarm	−06.0 to +25.0°C
13	Store 0_2 high alarm	00.00 to +25.0%0_2
14	Store 0_2 low alarm	00.0 to +25.0%0_2
15	Store CO_2 high alarm	00.0 to +10.0%CO_2
16	Store 0_2set point	00.0 to +25.0%0_2
17	Print store limits	
21	Store on and off	+ or −

Table 4 Cost distribution of six store automatic control system

Item	*% Cost*
Oxygen analyser with flow alarm	23
CO_2 analyser	11
Thermometer	5
Temperature probes (4 per store)	8
Computer	13
Software (1/10 cost)	8
Housings system assembly etc.	8
Manual switches relay interfaces etc.	7
Sampling equipment	6
Ventilation solenoids	3
Printer	8
	100%

Environment

Because of the need to keep the gas line short, it is necessary to have the equipment in close proximity to the stores. This invariably means the installation of the instrumentation in the engine room. This is a very electrically noisy environment because large capacity refrigeration plant is continuously being switched on and off. The engine room is usually a long way from the supply transformer and therefore the mains supply has many spikes and voltage variations. The voltage variations can be taken care of by good power supply design and great care needs to be taken in suppressing the mains input against spikes and transients.

All the electronic instruments and controls are housed in an enclosed rack system. The rack has a transparent door which can be locked. This protects the equipment from most of the dirt and dust and the heat produced by the oxygen analyser keeps the rest of the instruments warm thus protecting the equipment from dampness. The solenoid valves and sampling pump are contained in a separate wall mounting cabinet which is positioned as near to the stores as possible.

Costs

Table 4 shows a breakdown in percentage terms of the cost of the various items in a complete system for six stores. This does not include any installation work and the software cost has been amortized over 10 systems. It is interesting to note that the measuring instruments account for over 60% of the total and therefore it can be seen that full automation does not significantly increase the cost of a new fruit store complex.

Operational experience

Simple and clear documentation was devised so that the basic parameters were clearly set out for direct entry through the computer keyboard. The store operators found entry to be very straightforward and within a few days were confident enough to change the operating requirements as needed.

Despite heavy filtration of electrical noise some interference still got through causing false alarms and programme jumping every few days. Additional filtration was added which cured the problem.

One or two minor software bugs came to light after a few months of operation. These were easily cured by substituting the EPROM with one containing the revised programme. Both installations had mechanical type CO_2 scrubbers installed. This equipment, due to its method of operation always allows some oxygen to enter the store. Under some circumstances, the scrubber can allow too much air to enter and thus cause the oxygen to rise above the required level.

Unless the scrubbing system was adjusted so that too much oxygen was introduced by the scrubber the control system kept the oxygen in the store at the required level ±0.1% 0_2. The ventilation system with only the solenoid valves on the fresh air pipe is only just adequate when the store fans are on low speed. As a large part of the air is introduced by the scrubber it will be necessary to install forced ventilation in installations with dry lime scrubbing.

Conclusion

The success of any investment in new equipment whether high or low technology must in the long term be measured in economic terms. It must be left to the grower to decide if storing apples for longer and keeping them in better conditions produces sufficient return to finance the equipment necessary to achieve the objective. It is however certain that if he tries to achieve these conditions without the proper equipment, he is taking considerable risks which could result in total loss. Given the need and desire for longer term storage, a micro-computer controlled system can provide good reliable, comprehensive warning system and a large reduction in man hours in reading the store parameters. This can be produced at a cost comparable with a conventional control system.

Acknowledgements

I would like to thank Des Chappell and John Jameson of East Malling Research for their valued help and co-operation. I would also give my thanks to Mr Clive Charrington of Charrington's Fruit Farms and to Waveney Apple Growers who have purchased the two systems described in this report.

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Engineering in horticulture

Discussion on morning session

J C Turner (President) (Ryecotewood College) How long will it take to get the Sciray greenhouse into commercial production? **K E Morgan** — six carefully monitored customers this year probably followed by commercial production in 1982.

T C D Manby (NIAE) Mr Umpelby mentioned the successful work at NIAE (Hale 1978) but did not mention more recent work on the use of tangential fans these having shown desirable characteristics over variable heights and shapes. After all big blackcurrant bushes are as big or bigger than some types of top fruit tree!

R A Umpelby — certainly aware of the work but the brief for the paper was on soft fruit.

P Allington (MAFF) Queried the cost effectiveness in fuel/energy terms of expensive sophisticated engineering in the greenhouse. **K E Morgan** — experience very limited so far, it will be difficult to evaluate until the systems do go commercial.

B Finn (Chairman) Will the system of complete control outlined by Mr Burrage suit the new greenhouse designs? **S W Burrage** — yes.

J V Fox (Agric-Projects International Limited) This company is heading the consortium engaged in developing the Sciray project and agrees that careful monitoring is essential and is being carried out. The consortium recognises the system must not merely be cost effective but must be able to restore the commercial viability of glasshouse growing in northern Europe. The company is willing to keep interested parties informed of developments as they take place.

G Lawson (*Grower* magazine) For information the current cost of heated glass is £250,000/ha.

D J White (Chief Scientists Group, MAFF) Mr Umpelby implied that to compensate for machine deficiencies more pesticide is used than is necessary. To what extent is this of economic significance? **R A Umpelby** — any saving will be a benefit, for instance ULV sprayers may give 80% savings on costs of £250/ha. These are currently licenced for glasshouses but with the limited information on many chemicals savings are currently likely to be between ten and 20%.

Discussion after the final paper was opened by **Mr Peter Steer,** Fruit Specialist, Cambridge Division, ADAS, who highlighted points from all the papers finishing up with the following comforting statement. "We have seen today examples of the progress and ingenuity of the agricultural engineers, given the problems of our horticultural industry, some money of course, there is nothing beyond their capabilities".

Discussion on afternoon session

E Day (Pattenden Engineering Co Ltd) Asked Mr Shea if one day there will be a mobile hop picking machine which leaves the bine attached to the hill thereby increasing the crop by 15-20%. **M W Shea** — probably the suggested loss is too high. Plant breeders may produce a dwarf hop which will not need wirework and make a straddle machine possible. This may raise disease levels and so far dwarf hops have been poor croppers. Some advantage if bine could be used as a fuel.

R Stayner (NIAE). Confessed that he was not familiar with the horticultural industry but wondered about the effects of engineering developments on operator performance. How does a man know when his machine is running badly and has he the ability to do anything about it if he does know? **H Finn** (Chairman) pointed out that there are training schemes available to the industry. **R A Umpelby** — control systems are becoming more and more sophisticated especially for lower volume application but are expensive. On conventional sprayers the operator doesn't know until something positive goes wrong.

P Allington (MAFF) Computer control systems of the environment are ahead of the proven biological science which has been proven with outmoded equipment. We need more R & D to exploit the new possibilities. **S Burrage** — the grower is often ahead of the biologist but a precise tool may give quicker results, eg using a blue print. Sensors need to advance but infra-red thermometers for example could optimise our energy usage.

A low pressure irrigation system for orchard tree and plantation crops

P J Hull

Summary

A NEW system of irrigation developed for orchard crops at the US Department of Agriculture Salinity Laboratory in California and known as 'Bubbler' irrigation has recently been described by Rawlins (1977).

Since the method seems to offer many of the advantages of trickle irrigation without some of the disadvantages, a small demonstration unit has been installed in an apple orchard at the National College of Agricultural Engineering. It is on the basis of this experience, which formed part of a BSc final year project that the design and installation procedures described by Rawlins are discussed here.

Introduction

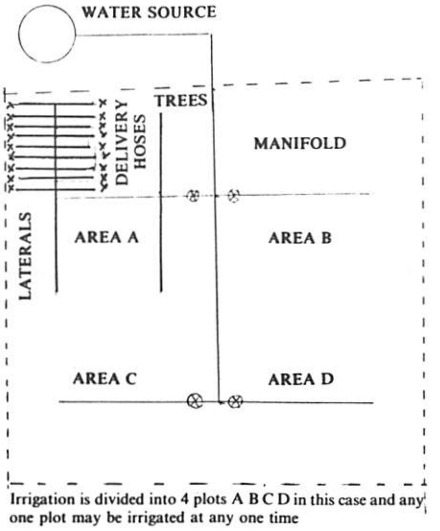
WATER is supplied to each tree in a row either side of a lateral by means of a delivery hose (fig 1). Laterals consist of thin walled corrugated polyethylene pipe of the type used for agricultural drainage, but unperforated. The diameter of the laterals depends on the size of the scheme but may range from 40 mm to 125 mm. Delivery hose diameters may also vary depending on the discharge required. Normally, all main, manifold, lateral and delivery pipes are laid below ground, the delivery hoses only appearing above ground level at each tree.

At each tree, the elevation above ground level of the discharge from the delivery hose will vary depending on the design of the system, the object being to adjust the elevation to obtain the same discharge at each tree. The delivery hoses are attached to wooden stakes near the tree to enable accurate measurement and adjustment of elevation. Tee pieces are used to maintain the outflow elevation, and at the same time direct flow to basins excavated at the base of each tree. This is done by installing the Tee so that an upper arm is open to the atmosphere to break the syphon effect (fig 2). The required elevation of outflow is calculated but later accurately adjusted when the system is in operation.

Advantages of the system

a) Higher flow rate and larger diameter pipes used result in fewer blockages, compared with trickle systems.
b) Elaborate filtration equipment is unnecessary and the associated head loss resulting in increased pumping costs is therefore eliminated.
c) Quality of the water is not critical.
d) Operates at low heads associated with surface irrigation systems.
e) Relatively low overall cost compared with other solid set systems.

Peter J Hull, Mechanisation Adviser, ADAS, Trawsgood, Aberystwyth, Dyfed.



Irrigation is divided into 4 plots A B C D in this case and any one plot may be irrigated at any one time

Figure 1 Bubbler imigration layout for a commercial overhead

Disadvantages of the system

a) Restricted to use on slight slopes (1 — 3% slope).
b) Limited to orchard and plantation type crops because of cost.
c) Possibly more leaching and evaporation losses than with trickle irrigation.
d) Usually greater water consumption than with trickle systems.

Basis of the design

The design is based on the calculation of total head loss due to friction in the lateral and in the delivery hoses. This is compensated for by adjusting the delivery hose elevation at each tree. Head loss calculations for the lateral are derived from fig 3 which is a log-log plot of Mannings Equation for flow in rough pipes. Head loss calculations for the delivery hose are derived from fig 4, a log-log plot of the Blasius Equation for flow in smooth pipes. Table 1 summarises the head losses in the lateral and delivery hose at each tree. Figure 6 is a graphical presentation of table 1 knowing the available head, head losses at each tree and the % slope down the lateral.

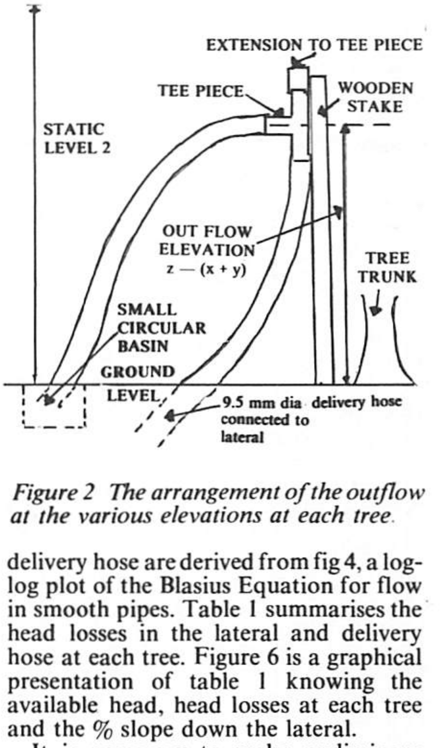


Figure 2 The arrangement of the outflow at the various elevations at each tree.

It is necessary to make preliminary calculations using a chosen flow rate and nominal size of pipe to ascertain head losses. Head losses, of course, must be less than the available head. Head losses are measured downwards from the static level (z) at each tree.

Procedure for calculating the head loss in sections of the lateral example

In the apple orchard at NCAE, a row of ten trees are spaced at 5 metre intervals. The land slopes at 2% away for the water

Figure 3 Head loss gradient as a function of flow rate for two sizes of corrugated polyethylene pipe

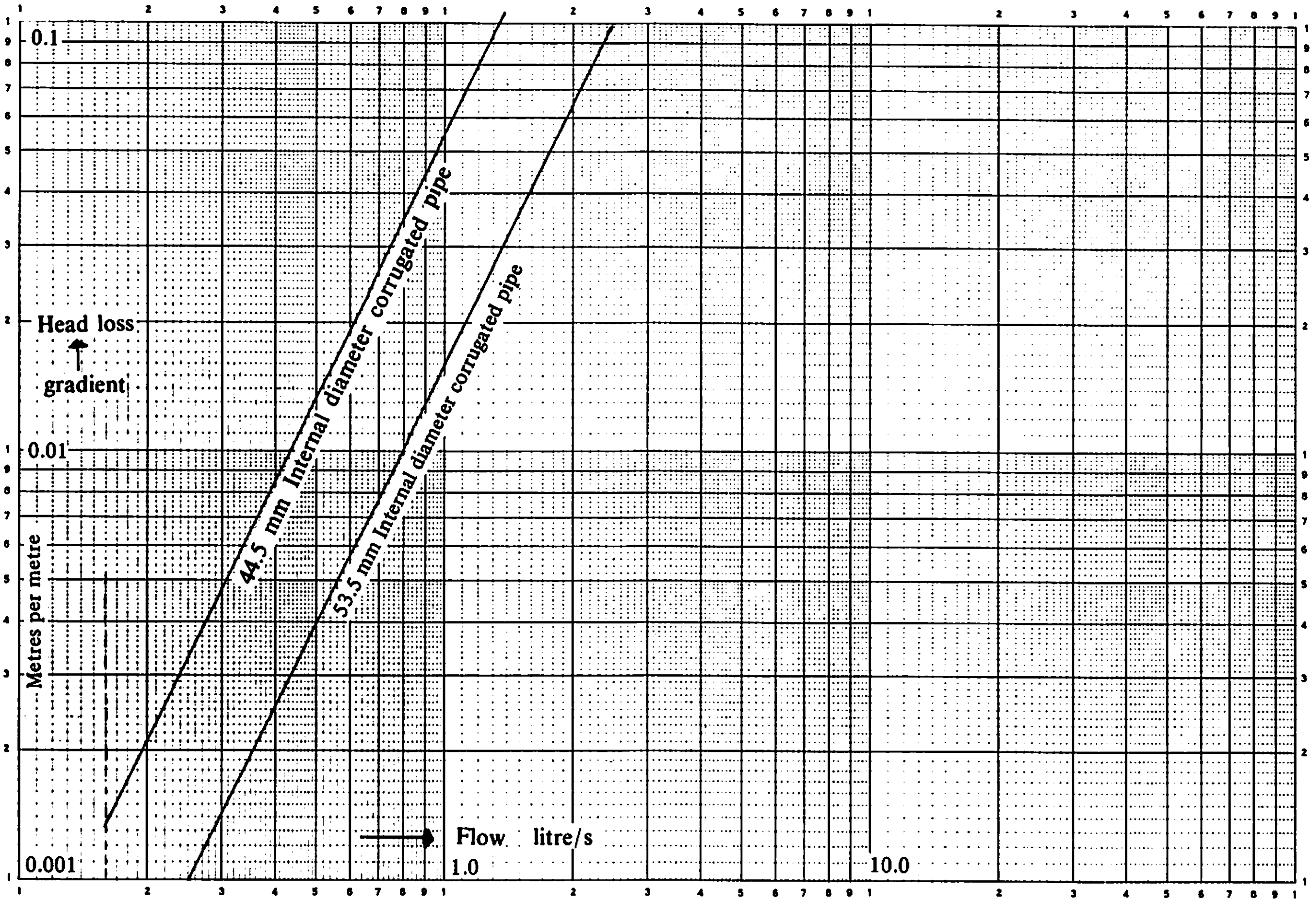
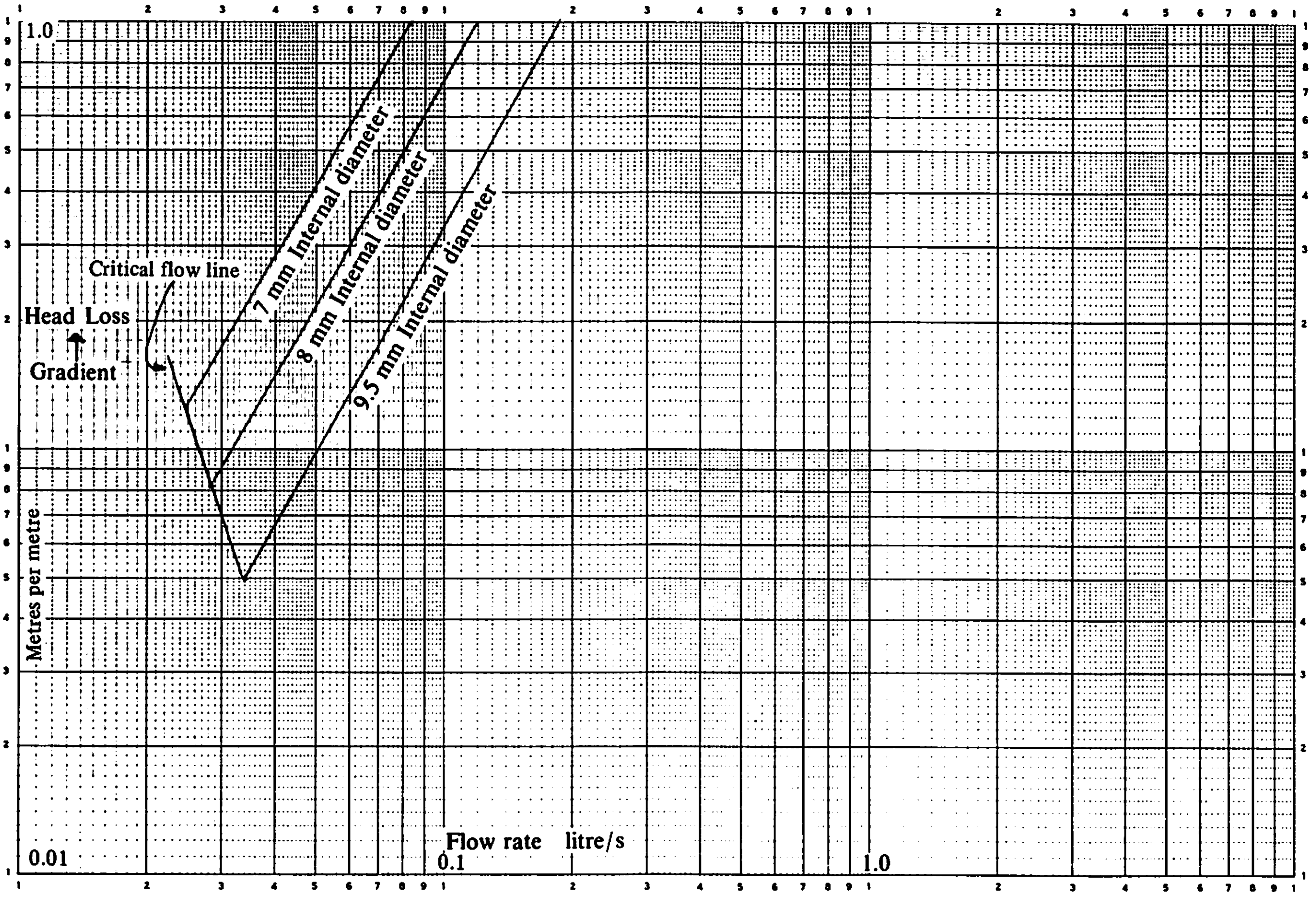


Figure 4 Head loss gradient as a function of flow rate for three sizes of smooth polyethylene pipe based on the Blasius equation



source. The available pressure head is 1 metre and the flow to each tree is 0.05 litres per second (litre/s). Figure 5 shows a diagrammatic representation of flows in the lateral. The greatest flow, and hence the greatest head loss occurs in Section 1, whilst the least flow occurs in Section 10 as the flow is fed off to each row of trees on either side of the lateral.

Critical flow

When using design charts, flows with Reynolds Numbers below 4000 must not be considered since flow-head loss characteristics are unstable. The diagonal cut off line, therefore, on the Blasius design charts represents a Reynolds Number of 4000.

Assembly and installation

Lateral — Manifold — Mains connections

Manufacturers of agricultural drainage pipe do not generally produce water-tight connections for laterals, manifold and main lines, and it is necessary to develop water-tight connections for these. This can be done by machining a groove in standard PVC pipe to take an O ring. The joint is secured by a high torque hose clip. If the system is developed commercially then proprietary fittings could be developed to facilitate easier connection.

Lateral — Delivery hose connections

Polyethylene has high creep characteristics and when a hole is made into the material it tends to be self-sealing. Based on Rawlins experience a tapered tool may be used to pierce the pipe on the crest of a corrugation to make the connection. The delivery hose is simply pushed into the resulting hole and the polyethylene eventually seals the joint around the pipe. It was also found that this type of joint does not leak at the small operating head used by the system.

Installation procedure

a) Find the reference level by raising all delivery hoses until no flow occurs in the system and water stands at the delivery hose exists.
b) Calculate the total head loss (x + y) in the lateral to each tree, making sure that this does not exceed the total head available at any tree. If it does then larger pipe sizes will have to be used to reduce head losses. Measure a distance (x + y) downwards from the reference level at each tree.
c) With the system operating, at each delivery hose in turn (ie other exits flowing) raise the delivery hose until no flow occurs. Now measure the distance y (0.5 m in this case) downwards from the reference level. This refines the system and allows for any discrepancies in x.
d) Measure the discharge at each tree to confirm the discharge expected.

Using 53.3 mm i/d pipe and 0.05 l/s flow rate to each free:— ,(below)

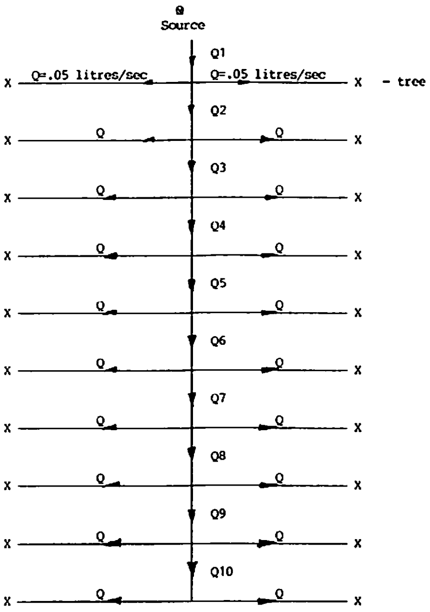


Figure 5 A diagrammatic representation of flows in each section of the laterals

For Section 1

Flow rate	Q_1	=	·10 x 2 x 0.5 l/s	=	1.0 l/s.
Head loss per m of lateral using fig 3	h_{f1}	=	0.0155 m/m		
Total Head Loss	H_{f1}	=	0.0155 x 5	=	0.0775 m

Head loss in the corrugated lateral pipe is 77.5 mm from reference level

x_1 = 77.5 mm

For Section 2

Q_2 = 9 x 2 x 0.05 = 0.9 l/s

h_{f2} = 0.0125 m/m

H_{f2} = 0.0625 m

The *additional* head loss in this section is 62.5 mm
Total head loss from reference level is 140 mm

x_2 = 140 mm

For Section 3

Q_3 = 0.8 l/s

h_{f3} = 0.01 m/m

H_{f3} = 0.05 m

x_3 = 190 mm

For Section 4

Q_4 = 0.7 l/s

h_{f4} = 0.0075 m/m

H_{f4} = 0.0375 m

x_4 = 227.5 mm

→ 58

The procedure for calculating head loss in the delivery hoses

All delivery hoses are the same length so that the head loss through each hose is the same at each tree for the same discharge rate (0.05 l/s). Assuming that 5 m of 9.5 mm (3/8 in) i/d polyethylene pipe is used, then the head loss gradient across the delivery hose at this flow rate is 0.1 metre/metre. The total head loss is 5 x 0.1 m = 0.5 m head loss for 5 m of delivery hose.

Table 1 summarises the head losses in the lateral and delivery hoses and fig 6 shows the information in graphical form.

Table 1 A summary of head losses at each tree location

Number of trees from outlet	1	2	3	4	5	6	7	8	9	10
Distance from water source (m)	5	10	15	20	25	30	35	40	45	50
Lateral head loss (x) from reference level (mm)	77.5	140.	190.	227.5	255.5	275.	287.5	295.	300.	300.
Delivery hose head loss (y) (mm)	500.	500.	500.	500.	500.	500.	500.	500.	500.	500.
Total head loss (mm)	577.5	640.	690.	727.5	755.5	775.	787.5	795.	800.	800.

Conclusions

The system is very sensitive to changes of pressure head and a constant head source is essential for a commercial orchard or plantation. A change in pressure head at the inlet to the system results in non-uniformity of application at each outlet. A pressure head of one metre is very small and small changes in head can thus have a marked effect on the flow rate at each outlet. The flow rate is fixed once the system is installed and is not easily changed.

A constant length of delivery hose is normally used for convenience in the calculations. Different lengths may be used at each tree to adjust head losses but this complicates design and actual physical limits must be borne in mind. For example, if the row width is 5 m and the lateral is situated in the centre of the row, a certain minimum length is required to physically convey water to the tree and up the tree trunk to its outlet elevation.

Whilst a small successful demonstration of the system was installed at the National College of Agricultural Engineering, there is a need to evaluate the system on a larger scale.

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For Section 5

Q_5 = 0.6 l/s

h_{f5} = 0.0056 m/m

H_{f5} = 0.028 m

x_5 = 255.5 mm

For Section 6

Q_6 = 0.5 l/s

h_{f6} = 0.0039 m/m

H_{f6} = 0.0195 m

x_6 = 275.0 mm

For Section 7

Q_7 = 0.4 l/s

h_{f7} = 0.0025 m/m

H_{f7} = 0.0125 m

x_7 = 287.5 mm

For Section 8

Q_8 = 0.3 l/s

h_{f8} = 0.0015 m/m

H_{f8} = 0.0075 m

x_8 = 295.0 mm

For Section 9

Q_9 = 0.2 l/s

h_{f9} = 0.001 m/m

H_{f9} = 0.005 m

x_9 = 300 mm

For Section 10

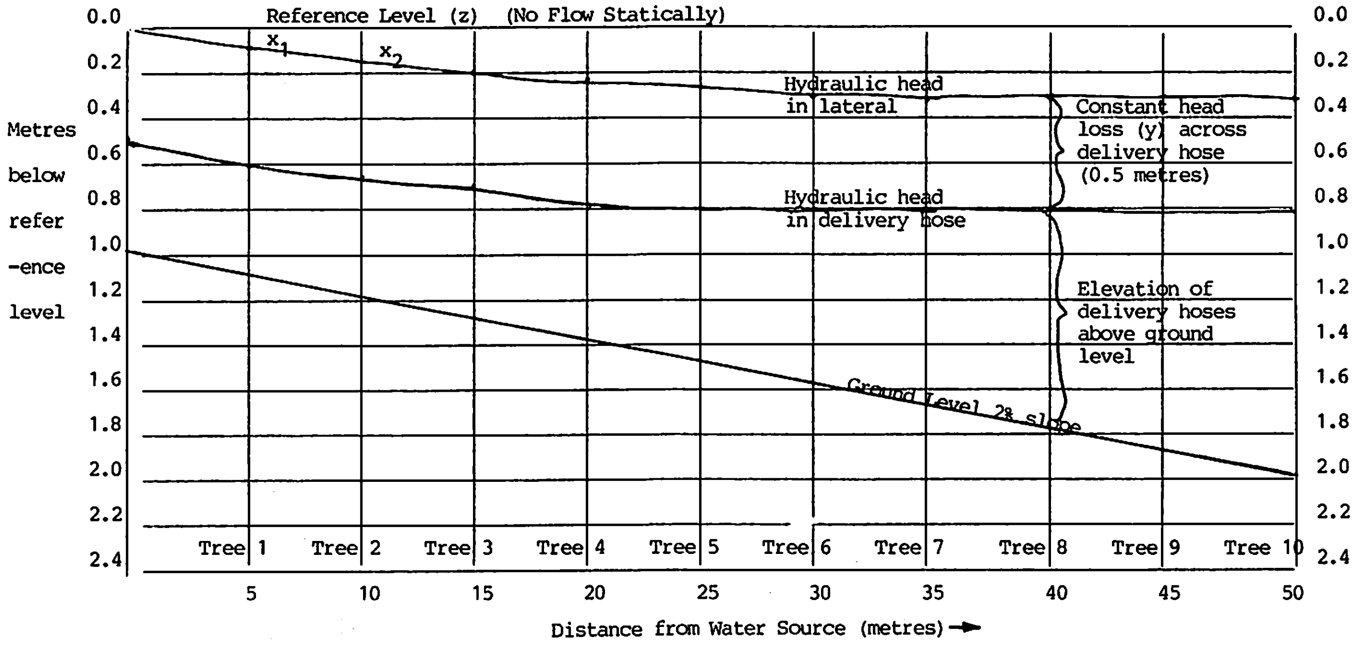
Q_{10} = 0.1 l/s

h_{f10} = negligible

H_{f10} = negligible

x_{10} = 300 mm

Figure 6 Hydraulic head, delivery hose outlet from ground level at each tree using 50 mm nominal "Icopal" drainage pipe and 9.5 mm i/d delivery hose



Ventilated winter storage of swedes (Brassica napus)

W J Elliot

Summary

MACHINE harvested swedes (7.66 tonnes) were stored outside at three levels of ventilation from November 1978 until March 1979. It was found that only limited ventilation is required to reduce temperature, higher levels of ventilation can lead to higher storage losses and mechanically damaged swedes do not store well even if ventilated.

Introduction

THE swede *(Brassica Rapa L)* is grown extensively for its thick fleshy so-called "root". The major value of swedes is currently as an energy source in ruminant production in Britain and Scandinavia[1]. The low dry matter content of 9-11% limits consumption by stock[3] and will present major problems as more sophisticated handling systems evolve.

In Scotland swedes can produce more metabolisable energy per hectare than any other agricultural crop in common production while the energy input for swede production is similar to cereals or intensive grass systems[2,4]. The ability of swedes to maximise energy returns may bring renewed importance to this traditional crop as current energy reserves are depleted.

Traditional harvest/storage systems

The simplest form of harvesting is "folding" similar to intensive pasture strip grazing with a portable fence moved by hand across the swedes to allow sheep or cattle access to only a few rows at any time. Even though no harvesting machinery is required, grazing wastage can be as high as 70%[5]. Total losses may be even higher with frost damage causing roots to break down. Severe poaching from stock grazing on wet fields can also harm soil structure and lower yields of subsequent crops, which are usually cereals. The most common harvesting/storage system practised in North Eastern Scotland is harvesting intermittently throughout the winter. Enough roots are stored to allow two to three weeks of feeding during the most severe weather. Difficulty in harvesting from wet soils is often experienced and as with folding, soil structure may be damaged.

Delays in harvesting roots can also lead to delays in tillage and drilling of the following crop[6]. This delay in sowing can lead to a significant reduction in grain yield.

Fresh yield of spring harvested swedes can vary from slightly higher to significantly lower than autumn yields, depending on variety and weather conditions. Many of the yield increases noted have been due primarily to absorption of water during the winter. Actual *dry matter* yields of spring harvested swedes have varied from a 1% increase to a 76% decrease compared with autumn yields[7].

In the South of Scotland a more common system of handling roots is to clamp most of the crop and feed it from the clamp throughout the winter. Only clean sound roots are recommended for clamping to minimise storage losses in an unventilated heap[6]. Losses in dry matter have been measured as high as 30%[8] with this system. Milder winters tend to lead to higher clamp temperatures followed by higher storage losses[9].

Proposed harvest/storage system

As with other cropping enterprises, most of the swede crop should be harvested during suitable autumn weather. Varieties giving maximum dry matter yield and having good storage qualities should be selected and stored in a large clamp. To overcome high storage losses from heating, ambient air cooling of the clamp similar to that in bulk potato stores[12] should be practised. The swedes could then be rationed throughout the winter in a uniform manner despite the vagaries of winter weather.

Experimental design and construction

An experiment was carried out during the winter of 1978/79 to study the problems associated with ventilated winter storage of machine harvested swedes.

A nominal half tonne capacity wooden pallet box was designed to let air enter through gaps in the bottom of the box. The sides and ends were as solid as the timber allowed to minimise air leakage. The outside dimensions of the box were chosen to match conventional straw bales which would be used for insulation. Each box held approximately 400 kg of swedes.

Twenty-four of these boxes were arranged along a centre tunnel containing two air ducts made from "lay-flat" polythene tubing (fig 1). The two boxes on each end were filled with roots but were not part of the experiment. Ten boxes had their bottom blanked off and received no ventilating air. Five boxes along the first half of the tunnel were ventilated by a 750 watt centrifugal fan and received an estimated 110 $m^3\ h^{-1}\ m^{-3}$ (120 $ft^3\ min^{-1}\ t^{-1}$) airflow through the boxes. Five boxes along the second half of the tunnel were ventilated by a 375 watt centrifugal fan and received an estimated 45 $m^3\ h^{-1}\ m^{-3}$ (50 $ft^3\ min^{-1}\ t^{-1}$) rate of ventilation.

The boxes were separated and surrounded by a single layer of straw bales to serve as insulation.

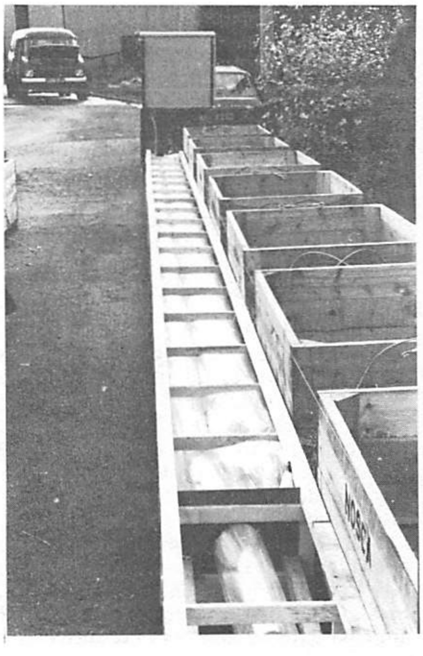
Each fan was operated by its own electrical controller which would switch the fan on when the average box temperature was above 2°C, and the ambient air temperature was cooler than the average box temperature but above -2°C. A digital clock was added to each controller to record the hours of fan running time.

Monitoring equipment and methods

The fan controllers were checked weekly to note the hours each fan had operated.

In addition to the twelve temperature probes for the controllers, an additional

Fig1 Layflat tubing in position in main duct inflated just prior to cutting slots in bottom where required. Ventilated swede storage experiment, November 1978



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five thermistor probes were placed in unventilated boxes to monitor root temperatures weekly. The four centre boxes, two unventilated, one with low ventilation, and one with high ventilation, each had a temperature probe from a continous chart recorder.

Wire ropes were attached around the ends of all the boxes to facilitate lifting for monthly weighing. A two tonne capacity spring balance attached to a boom on a foreloader was used to lift the boxes for observing weights. An empty box was included at the edge of the experiment to take the readings. Samples for chemical analysis were taken by coring 60 roots prior to storage in November 1978 and 150 roots at the end of storage in March 1979. Disease observations were made by a plant pathologist in December 1978 and January 1979 and were quantitatively evaluated in March 1979.

Swedes stored

Ruta Øtofte swedes, a high yielding medium dry matter variety, were harvested on 9 November 1978 using a single row Reekie swede harvester. They were carted to the experiment site where a grain bucket on a tractor foreloader dumped the roots into the boxes. Large stones and badly diseased roots were sorted out by hand. It was noted that the harvester had severely damaged almost half the roots.

Results

Temperature

At no time during the storage period was there any significant difference in temperatures of the two ventilated treatments. During December and at the end of February both ventilated treatments were significantly cooler than the unventilated boxes. Average temperatures from November to the end of March are noted in table 1. The fan operating hours are also included in the table.

Changes in mass

From the monthly weight observations the average mass as a percent of initial mass was calculated. In every month the high ventilation treatment percent was significantly less than the low ventilation and unventilated treatments (see table 2).

The fresh weight increased during the storage period but the actual total dry matter decreased in all treatments. The high ventilation treatment dry matter yield was significantly lower than the other treatments. Table 2 summarises the changes in fresh weight and dry matter. It also includes data from the results of the 1978/79 over-wintering trials by the Crop Husbandry Division ([10])..

Disease analysis

In December an initial observation was made of all boxes for disease while the boxes were uncovered for weighing. Types of diseases were noted. Samples were collected from the end boxes on 10 January to be taken to the laboratory for positive identification of disease and level of infection.

Following the final weighing in March, a detailed analysis of disease levels in one box from each treatment was carried out. From each box the entire contents of approximately 250 roots were sorted into mechanically damaged and undamaged categories.

Surface levels of infection were estimated for each individual root on a 0 to 100 scale. The root was then cut in half and internal levels of infection were rated between 0 and 100. It was also noted whether the disease was bacterial or fungal.

In two other boxes from each treatment twenty five to thirty roots were selected at random from each box and types and levels of disease noted as above.

A "disease index" was then calculated similar to methods used to quantify potato damaged using the following formuli:

(Number of roots with external disease x 1

+

Number with internal disease less than 10% x 3

+

Number with internal disease between 10% and 50% x 5

+

Number with internal disease greater than 50% x 7)

÷

Total number of roots in sample.

These calculated disease indices are summarised in table 3 comparing disease indices for various levels of ventilation and for effects of damage.

Table 1 Average temperature and total fan operating hours for the ventilated swede storage experiment from November to March

Treatment	*Average temperature (^oC)*	*Fan operating hours*
Unventilated	6.6	
Low ventilation	5.0	1240
High ventilation	4.8	1045

Table 2 Yield of Ruta Øtofte swedes expressed as per cent of yield on 10/11/78.

Treatment	% Fresh weight		% Dry matter
	7/2/79	7/3/79	7/3/79
Over-wintered			
Craibstone	N A		87
Elsewhere			60
Stored			
Unventilated	110	107	89
Low vent	107	105	87
High vent	98	94	81

Table 3 Mean disease indices for different ventilation treatments and different levels of mechanical damage. Swede storage project, November 1978 — March 1979.

Treatment	*Disease index*	
No ventilation	2.77	
Low ventilation	2.77	
High ventilation	3.44	N S
Undamaged roots	1.815	* *
Damaged roots	4.408	

N S — Not significant difference
*** — Significant difference with 99% confidence*

The type of infection (bacterial or fungal) is summarised in table 4 which shows the average per cent of incidence of each type of disease for the ventilation treatments and for effects of damage. Some roots had both types of infection present.

Discussion of results

Temperature

Because of the very low ambient temperature during January and February 1979 there was no difference in box temperatures. It was only during the warmer weather of November and December 1978 and the end of February 1979 that the ventilated boxes were

Table 4 Per cent of each type of infection present in Ruta Øtofte swedes at different levels of ventilation and damage. Analysis made after four months of winter storage during 1978/79 at Craibstone[13].

Treatment	*Type of infection*		
	None	*Fungal*	*Bacterial*
No vent	33.66	44.44	27.04
L vent	38.25	49.06	22.06
H vent	27.26	57.44	22.84
Damaged	13.06 } **	64.14 } **	27.79
Undamaged	51.09	29.39	20.50

*** — Percentage significantly different with 99% confidence* significantly cooler than the unventilated boxes. Olorunda found clamp temperatures generally warmer in roofed, small unventilated clamps during the milder winters of 1971/73[9].

The straw bales that surrounded the boxes became saturated with water during the heavy rains of December. For the remainder of the storage period they felt much warmer than the swedes and contributed to keeping the roots warm in spite of low ambient temperatures. The heat and moisture of the straw may have contributed to levels of bacterial activity particularly in unventilated treatments.

In only one box was any freezing noted. This occurred following the January weighing when the top straw bales were not replaced properly over the box.

The final box of the high rate ventilated boxes was warmer than the others in that treatment in all readings taken after 1 December 1978. When the experiment was dismantled in March 1979 it was observed that the large polythene ventilation duct had been partially blocked by wet straw falling on it. This probably limited the ventilating air entering the box and would account for the constantly higher temperatures as well as a lower observed loss in fresh mass.

The recommended 2° Celsius storage temperature[11] was never really achieved. Usually when ambient temperatures were much below swede temperatures they would be below 0° Celsius and the controllers would stop ventilation. To try to overcome this the controllers were set to -2°C but this still did not provide adequate cooling air. The only day temperatures did get below 2°C was after a night of very low temperatures and a strong wind blowing directly into the fan inlets.

Discussion on changes in mass

The 7-10% increase in fresh mass in the low ventilated and unventilated treatments was probably due to absorption of rain water following the heavy December rainfalls which soaked through the surrounding straw bales and wet the surface of the swedes.

It was noted that the high rate of ventilation gave significantly lighter treatments during every weighing. With the higher rate of airflow a certain amount of desiccation was expected ([11]) but the source of the dry matter loss require further investigation. The only indications of the source of this higher loss are the higher disease index and higher level of fungal infection for the high ventilation treatment. Neither statistic was significant however.

With the relatively harsh winter the field losses of Ruta Øtufte swedes varied from similar to stored roots to much higher losses than observed with stored roots, depending on the location of the trial[10].

The dry matter losses of all treatments were low during the 1978/79 Winter compared with earlier observations of stored swedes [8,9]. Because the winter was much colder than most this result was to be expected. A milder winter may have led to higher storage losses.

Discussion on disease observation results

The effect of ventilation on calculated disease indices was not significant (see table 3). This was probably due to the severe damage inflicted on the roots by the harvester overshadowing any difference from ventilation. The effects of mechanical damage on storage are already well documented for unventilated storage [1,6,9].

This experiment was designed to test if ventilation could improve storage of machine harvester swedes. However it was decided to analyse the effect of damage when it was observed at the final weighing and from disease analysis that diseased roots had usually been mechanically damaged. Since damaged roots are more susceptible to disease it would appear that ventilation is no substitute for careful harvesting and handling if long term storage is required.

Several interesting possibilities arise from the type of infection noted in table 4. The only area of statistical significance was that fungal infections were greater in damaged swedes than undamaged swedes. This had always been the case in traditional unventilated storage[6].

Although statistically not significant, the lower levels of bacterial infection in the ventilated treatments compared to the unventilated treatments could be explained by noting the significantly lower storage temperatures. With most vegetable storage high bacterial activity is associated with higher temperatures[11,13]. Greater amounts of surface moisture were also observed in the unventilated treatments and this could also aggravate bacterial deterioration as it is known to do in potato storage[11].

The higher levels of fungal infection noted in the ventilated treatments may have been the result of the lower temperatures of those treatments. Certain species or moulds are known to thrive at lower temperatures in potato storage[11]. No "curing" period was allowed at the start of storage for the ventilated treatments. This practice of allowing the produce to warm up to about 10° Celsius for ten days is common with potatoes ([11]) to allow surface wounds to heal. It was noted that fungal infections were significantly more extensive on mechanically damaged roots and it follows that they may also have been more extensive on swedes that had not had a curing period to allow any minor wounds to heal. Further research in this area may confirm whether swedes in storage benefit from a curing period.

Certain fungal infections are also more common at lower humidities (90-95% RH) than bacterial diseases which thrive above 95% RH[13]. Increasing levels of fungal infection were observed with increased ventilation rates, which would have given a less humid store environment during ventilation periods.

Observation of disease levels in early January indicated the presence of all diseases noted in March but very few seriously diseased roots were observed.

Conclusions

1. Mechanical damage inflicted on swedes during harvest, transport and handling can lead to higher levels of disease in both unventilated and ventilated storage.
2. Forced draught ventilation may have little effect in reducing storage diseases with mechanically harvested swedes.
3. Ambient air cooling can reduce temperatures of swedes stored during the winter but an airflow of 110 m^3 h^{-1} m^{-3} (120 cfm/t) does not provide significantly cooler storage than an airflow of 45 m^3 h^{-1} m^{-3} (50 cfm/t).
4. High rates of ventilation can increase dry matter losses in stored swedes.
5. During a harsh winter stored swedes will have losses similar to or lower than swedes overwintered in the field but will be available for feeding regardless of weather conditions.
6. A storage temperature of 2° Celsius cannot be achieved for any length of time with ambient air cooling alone.

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INSTITUTION FORTHCOMING NATIONAL CONFERENCES

DEVELOPMENTS IN THE MECHANISATION OF CEREALS PRODUCTION.
Tuesday, 10 November 1981.
St Ivo Centre, St Ives, Cambs.
(In association with the Agricultural Development and Advisory Service (Eastern Region) and South East Midlands Branch of the Institution).

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ENGINEERING FOR MEAT PRODUCTION.
Tuesday, 16 March 1982.
National Agricultural Centre, Stoneleigh.
(In association with West Midlands Branch of the Institution).

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ENGINEERING DEVELOPMENTS FOR THE HANDLING AND STORAGE OF CEREALS.
Tuesday, 11 May 1982.
National Agricultural Centre, Stoneleigh.
(Institution Annual Conference).

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STRAW PROCESSING.
Tuesday, 12 October 1982.
Essex; exact venue to be advised.
(In association with South Eastern Branch)

* * * * * * *

MECHANISATION OF POTATO PRODUCTION.
Tuesday, 15 March 1983.
Scotland, exact venue to be advised.
(In association with Scottish Branch).