The AGRICULTURAL ENGINEER

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Editorial, Advertisement and Institution Offices:
Penn Place, Rickmansworth, Herts. WD3 1RE

Telephone:
Rickmansworth 76328

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Front cover: Andrew T. Pepper, best final year student of field engineering receiving the Hunting Cup from the Rt Hon The Lord Luke at the National College of Agricultural Engineering Seventh Commemoration Day at Silsoe, on 4 July.

Progress and Problems in Mechanisation Development*

THE overall effects of mechanisation on labour productivity in agriculture are reflected in the relationship between numbers of workers and volume of output. The average increase in labour productivity over the period 1964-71 has been officially estimated at 6 per cent per annum†. About half of the improvement can be attributed to advances in mechanisation, and the rest to expansion of output due to other scientific or technical advances. The improvement trend continues, but each increment of further improvement tends to be less easily justified on economic grounds.

The broad picture concerning numbers of workers is shown by the following figures:

Regular Whole-time Workers

Year (June figures)	*United Kingdom*	*England and Wales*	
1950	717,000	575,000	
1969	308,000	250,000	
		Employees	*Family Workers*
1970**	273,800	167,000	50,600
1971	267,100	162,700	50,700

***Numbers from 1970 onwards are not exactly comparable with those for earlier years owing to inclusion of managerial and secretarial workers, definition of "regular wholetime", etc.*

The number of whole-time workers was more than halved between 1950 and 1968, but this rate of decline could obviously not be maintained indefinitely. The rate of fall in numbers of regular whole-time workers ran at 6-7 per cent per annum from 1964-66, and about 5 per cent per annum from 1967-70. The current rate of outflow is estimated at about 3 per cent per annum†. Since 1970 separate figures have become available for employees and family workers in England and Wales.

Future trends will depend on many factors, including the wages and working conditions of agricultural workers compared with those of workers engaged in other industries. There are already few workers who are not machine users rather than manual workers; and one of the factors which will make specialisation in production systems increasingly essential is the need for workers to be skilled in the use of a limited number of machines, successive generations of which tend to be more complex and to have a steadily increasing output.

I need hardly say to this audience that most farming operations can be classified as some form of materials handling, and that there are two major reasons why men and women will supply an ever-decreasing proportion of the energy needed for getting farm work done. The first reason is economic. Considered in isolation, the power supplied by human muscles costs at least a hundred times that provided by an internal combustion engine or electric motor; so use of human energy has to be confined to situations where mechanical power cannot be effectively applied. The second important reason is sociological. Farm workers will increasingly object to forms of physical work which are unnecessary and also unpleasant. One of the more important progressive changes is the steady increase in the amount of mechanical power available on farms. There are more farm tractors than whole-time farm workers; and it is not uncommon for a man to use two tractors to carry out a complex harvesting or handling job. Electrical power is widely used about the buildings for a very wide range of jobs that were formerly done by hand. Some jobs can be arranged with automatic controls so that human supervision is eliminated or minimised; and in these circumstances very high productivity is attainable, though sometimes at a substantial capital cost.

On the whole, mechanisation developments to date have been achieved at a very reasonable cost. The effects of mechanisation on farming expenses during a 10-year period in the "sixties" are roughly illustrated by figures from the "Review" White Papers.

Farming Expenses, England and Wales

	1959-60		*1969-70*	
	£ million	*per cent of total exp.*	*£ million*	*per cent of total exp.*
Labour	312½	25	342	19
Machinery	221	17½	287	16
Total expenses	1,266½	—	1,839	—

Over this 10-year period, increased expenditure on machinery, averaging about 2½ per cent per year, was effective in keeping the average increase in labour costs down to below 1 per cent annually. Other costs such as feeding stuffs rose at a much higher rate.

* *Presidential Address presented by C. Culpin at the Annual Conference on 9 May 1972.*

† *Annual Review and Determination of Guarantees 1972. Cmnd 4928. HMSO, London.*

These are substantial achievements, and they indicate the importance of a continuation of the trend towards increased labour productivity.

During this period bulk handling of grain from the field almost entirely superseded handling in sacks; hand labour was almost completely eliminated from sugar beet harvesting; tractor driven spreaders took over from manure forks; and many livestock farming jobs such as milking and feeding were transformed on the most progressive farms. Many jobs such as bale handling, selective vegetable harvesting and fruit picking continued to require much hand work, but the beginnings of a further revolution could be detected.

Size of Enterprise

Improvements in labour productivity are considerably influenced by size of enterprise. In this aspect, Britain has a considerable advantage over most other countries of Western Europe. For example, the average size of dairy herds in *UK* and *EEC* countries in 1968 was as follows:

Country	*Average cows per herd*
Netherlands	12
Denmark	11
Luxemburg	9
Belgium	8
France	8
W. Germany	6
EEC average	9
UK	28

Almost half of the dairy cows in Britain are now in herds of 50 or more, compared with an average of about 4 per cent in this size group in *EEC* countries. Closer contact with Europe will therefore not of itself provide rapid solutions of development problems in dairy farming. On the other hand, the number of herds with over 50 cows in the *UK* is only about 19,000; so the size of the home market for new equipment is restricted, and there is obvious potential for increased equipment sales abroad if, as seems likely, the need for improved labour productivity there brings about a substantial increase in the number of large-scale enterprises.

Britain has similar advantages over most competitors in the size of other livestock production enterprises and also in some other aspects of agricultural production. For example, over 50 per cent of our quite considerable production of Cox's Orange apples and of Conference pears comes from a relatively few holdings with over 70 acres of each of these varieties. This means that though the number of potential customers for new types of equipment is falling, the size of individual enterprises is sufficient to justify the use of some very expensive machines for production and preparation for market.

I do not think that agricultural engineers need at this time worry unduly about predictions that medium-sized and family farms in Britain will rapidly be superseded by very large-scale farming companies. We shall be better occupied in the pursuit of developments, such as automatically controlled feeding systems, which make it easier for relief workers to carry out their functions satisfactorily. I know that the mere mention of automatic control usually results in a chorus of "What about stockmanship?"; but all the evidence that comes my way suggests that livestock thrive best in conditions where automatic control systems are properly designed, installed and operated. There should be many important developments in this field in the near future.

Origins of Progress

It is not my intention to say more about the extent of progress achieved. Rather, I want to draw attention to some of the origins of progress, and to warn against the kind of complacency which leads to the false assumption that nothing more needs to be done to maintain the impetus of progress.

New Ideas and Inventions

Mechanisation progress comes from many sources. Many important developments are a direct result of farmers' ideas and of the trials which they carry out to see if the idea will work in practice. Such efforts are almost invariably backed up at a fairly early stage by a manufacturer, usually a small one, who is prepared and able to construct a machine first and get down to details of design later, if the preliminary trials are successful. Some advances are the result of detailed design studies and testing by established manufacturers. We must continue to look mainly to such origins and to the results of inventions developed in similar ways which come from other countries. But it would be a mistake to suppose, because of this, that nothing is required from official sources. On the contrary, in looking for the origins of progress we must examine many important aids to rapid development. Among these the most important is the provision of reliable information.

Information

The provision of information on machine performances is no new idea. Those who are interested in some early efforts to meet the need could do worse than read early volumes of the *Journal of the RASE*, such as that for 1871 in which the results of the "Trials of Traction Engines at Wolverhampton" are reported. Much later, the need for reliable information on the new equipment for carrying out essential work was a major factor leading to the creation of the National Institute of Agricultural Engineering. Can it be seriously argued that the need for similar information has now disappeared?

It is to be hoped that even if all of the recommendations of the Rothschild Report** on Government Research and Development are not accepted, the discussions about the objectives of Government *R* and *D* will at least lead to re-consideration of the cost/effectiveness, from a national viewpoint, of

** *A Framework for Government Research and Development. Cmnd 4814. HMSO, London, 1971.*

various methods of providing information on implement and machine performances. Experience has shown that well-planned agricultural machinery testing provides the raw material, not only for advice to farmers on planning of mechanisation systems, but also to those engaged on developing new machines or systems, whether in Government establishments or in commercial manufacturing firms. I shall return to this subject later.

Development

When a new technique has been sufficiently proved, the rate of its adoption depends on many factors: some of these are strictly commercial and private, but one important factor is the part played by official services. Let me give just one example out of the many which attracted the attention of the Ministry's advisory services, and is now history.

Some simple experiments carried out by the *NIAE* showed that drying grain in bulk in ventilated bins could form the basis of an attractive new system. The Institute was closely concerned with a prototype farm plant which proved that the idea could work well in practice: but manufacturers were not convinced at this stage. Years of delay in adoption were eliminated by *NAAS* bringing the facts to the notice of interested farmers and by helping them to overcome the many practical problems that existed before well-designed "package deals" were offered. Initial mistakes were soon rectified, and many thousands of farmers who needed bulk storage as well as drying benefited by adopting the system.

Later, when storage costs rose and the advantages of using multi-purpose buildings became apparent, the attractions of bulk drying "on-the-floor" were made available to farmers in general within a year of one farmer sorting out a simple system of air control and grain handling. Manufacturers had by then learned to trust the judgement of *NAAS* mechanisation advisers, and they quickly produced improved main ducts, branch ducts and packaged drying units. The rapid adoption of on-floor drying which resulted could not have taken place without the provision of reliable basic technical information by a service which was clearly independent of trade interests and concerned only with improvement of agricultural productivity for the benefit of farmers.

Education and Training

In considering origins of progress, I should mention the part played by this Institution in assisting the supply of professional agricultural engineers. We are now so accustomed to the availability of staff with a degree or National Diploma in Agricultural Engineering that it is easy to forget that the essential high levels of agricultural engineering education were not obtained without a struggle. In pursuit of its goal of ensuring that professional agricultural engineers of all grades secure appropriate national recognition, the Institution has taken a full part in the activities of the Engineers' Registration Board. Registration is now open to our members who are suitably qualified for the Technician-Engineer and Engineering Technician grades; and though our Fellows do not yet have the satisfaction of national recognition as Chartered Engineers, we believe that our standards are as high as those of most of the 15 chartered institutions, and that such recognition is now due. Today, men with agricultural engineering training are still not being used as widely as they should. For example, though it is clear that development of improved mechanisation systems is one of the most important tasks that some experimental farms could undertake, their ability to develop such work is restricted by the fact that the senior staff is based on "husbandry" men or agricultural scientists and does not include professional agricultural engineers.

Planning for Higher Efficiency—Some Practical Problems

Total farming expenditure under the heading "Machinery Expenses" includes about £127 million spent annually on new equipment, of which about £40 million is on tractors.

When a farmer is about to buy new equipment he needs to be able to make reasonably accurate comparisons between performance of his present equipment and that available to replace it. There is usually some reliable information available on tractors, because the reputable manufacturers know that they cannot for long succeed in world markets without having their products tested to a standard code at one of the independent national testing stations. The tests can be criticised for lack of information on durability and performance in practical farming conditions; but at least they provide facts concerning engine power and several other important engineering details.

The situation concerning information on implement and machinery performances is very different. It is characteristic of most agricultural machines that there is a vast difference between "spot" and "overall" work rates; and as a general rule there is no reliable means of comparing manufacturers' claims without resort to comparative practical trial. Here we come to a problem—possibly the biggest mechanisation problem of today. A scheme of "Testing for Users", which had many good features but suffered from some problems of organisation, has been wound up. Even the reasons for ending the scheme are a matter of argument rather than undisputed fact. All that I wish to say on this is that though the scheme was not worth keeping alive at the time when it was abandoned, the work done in earlier years had proved the potential value of this type of work when pursued with skill, enthusiasm and integrity.

There are honest differences of opinion on the value of testing, and I should not be drawing attention to this subject today if I was not certain that sooner or later a means of providing more reliable information on machine performances must be found. I therefore propose to examine the problem briefly in order to see if this Institution can help in any way towards a solution.

Basis of Need for Information on Machine Performances

Some considerations concerning the need can be summarised:

1. Efficient mechanisation is vital to efficiency of most agricultural production processes. From a national productivity viewpoint, mechanisation development is equal in economic importance to all other technical and scientific developments. From the individual farmer's viewpoint, efficiency of mechanisation is vital.
2. There has never been an end to mechanisation development in the past, and there will be no end to it in the future. Equipment and methods that are satisfactory today are certain to become obsolete sooner or later. The pace of economic progress depends on a reasonably rapid adoption of new and more economic systems.
3. It is possible by "systems engineering" to make hypotheses concerning machine performances and to work out efficient systems on the basis of such hypotheses: but practical application of systems engineering, whether the technique involves use of a computer or just the farmer's brain, can only succeed if reliable basic information on machine performances is used.

Example of the Need

I hesitate to illustrate the need by reference to a subject as complex and difficult to quantify as soil cultivation, when I could more easily cite fast-developing equipment for many important mechanical handling or harvesting jobs such as silage feeding, dispensing concentrate feed in dairy parlours, bale handling, potato harvesting, etc. I have chosen the more complex subject in order to emphasise the fact that even for those farming operations which are basic to crop or stock production, there are changes of background conditions with the passing of time which lead to a necessity to change farming tactics.

On many arable farms efficiency in dealing with the peak of autumn work is the technical factor most likely to influence profitability. A pre-requisite for success is often timely completion of corn and root harvests. Always there is a fundamental need to get autumn cultivations and drilling done in good time. A vast amount of experimental work has shown conclusively that there is no particular magic in ploughing, and that it is often easier to apply the power of modern high-powered tractors effectively if other techniques are substituted for the traditional plough-cultivate-drill system. The advent of paraquat has contributed to the trend to more frequent omission of ploughing. I need not go into detail on "no-ploughing" techniques. Basic agricultural tasks in a typical case where wheat follows corn are:

a. The earliest possible breaking of stubbles, or in some cases herbicide spraying, to prevent weeds becoming strongly established after removal of the crop; and any necessary further operations to secure effective weed control.
b. Even distribution of seed and possibly application of fertiliser as near as possible to mid-October or such other date as particular situations require. The seed should be covered by friable soil. Soil structure cannot and need not be accurately specified, but excessive compaction and smearing should be avoided.

The typical questions which face Mr Typical Farmer, who has arrived at the time when his 50 hp main cultivating tractor needs to be changed, are:

Will it be worth while to go up to the 70 hp class or above? If he does, what will be the effect on his implement needs? Assuming, as is likely, that he decides in favour of the more powerful tractor, will he need a new plough?

He may well decide to manage with the old one and to put more emphasis on tined implements. So he needs to choose the most suitable cultivator. He needs to know:

What are the characteristic results of using the main types of cultivator on his soil type(s)?

Should he seek an implement with rigid, substantially vertical tines; rigid steeply-raked tines; rigid C-shaped tines; spring-mounted C-shaped tines, or C-shaped spring tines?

How many tines and how wide?

What overall work rate can he expect?

He will be lucky if he can obtain positive answers to these fairly simple questions.

For the later operations of seedbed preparations and drilling, the scope of the questions is wider, and the information even less likely to be obtainable by persistent questioning. He needs to consider:

Should he continue with his conventional methods, which may be discing or cultivating followed by combine drilling, or should he be thinking of a combined cultivation and drilling operation? What combined techniques are a possibility and will they suit his soil conditions?

What work rate can be reckon on if he decides to use a combined cultivator/drill?

Will it be effective following the prior cultivation that he favours?

What performance can he expect from a combined rotary cultivator-seeder combination, and is his soil suitable for this machine?

What are the possibilities of a commercially available power harrow/drill combination of the type experimented with by *NIAE*?

It may not be possible to provide positive and clear-cut answers to all questions, but at least it should be possible to provide properly qualified answers to most of them. Such information is essential to the next step, which is the planning of an efficient co-ordinated seasonal work programme. This, however, is a separate subject which is being worked on by *ADAS* mechanisation officers in conjunction with *NIAE*, and which will, I am sure, be widely appreciated by farmers when the basic data on implement performances are available. In the meantime, anyone interested in combined cultivating and drilling operations needs to keep in mind the over-riding importance of drilling at somewhere near the optimum time. For this reason, combined operations which are labour-saving but very slow may have to give way to techniques which enable some of the soil preparation work to be done while it is still too early to drill.

I hope I have said enough to convince any doubters that more information on the performance of a wide range of cultivation implements and commercial combined machines is urgently needed.

Study of Ways of Meeting Information Needs Required Now

It might be argued that it is too soon after the ending of the scheme of "Tests for Users" to start considering how shortcomings of the earlier scheme could have been overcome, or how the needs which I have briefly indicated should be met; but, in fact, everything points to the opposite conclusion. Proposals for new ways of deciding priorities for applied work by government stations are being discussed; dealers and distributors are missing independent information just as much as farmers and advisers; manufacturers are finding the "full cost" basis of charging for confidential tests a real barrier to progress; and the few investigations carried out by *ADAS* mechanisation officers are highly valued. Practically all major European countries have flourishing government-sponsored testing schemes; and one of the reports of the Canadian Royal Commission on Farm Machinery† assembles some strong arguments for increasing government expenditure on the supply of independent information on machine performances. No doubt re-consideration at this time could lead again to the kind of arguments which helped to end the old testing scheme; but if the suggestion which I shall make were adopted, I do not think that there would, in fact, be any serious disagreement on major objectives.

A New Study of Objectives by the Institution

I should not have thought myself justified in devoting a substantial proportion of this address to lack of information on machine performances if my only purpose had been to criticise the existing situation, or if securing more independent information were in any way harmful to the long-term interests of any section of our membership. My purpose is, in fact, to suggest a first step towards securing some improvement.

I believe that the present unsatisfactory situation has developed partly because there has never been a sufficiently clear definition of technical objectives; and I am certain that at least some of the past objections to comparative tests were a result of insufficient knowledge of methods employed and of precautions that were or could be taken to overcome such difficulties as the variability of agricultural crops and conditions.

† *DONALDSON, G. F. 1970 Farm Machinery Testing. Royal Commission on Farm Machinery (Canada) Report No. 8.*

The active membership of the larger branches of this Institution embraces manufacturers, dealers, farmers, advisers, teachers and sometimes research workers. Within each type of occupation there are men who certainly have views and some specialised knowledge on their own information needs. With good leadership, which I am sure such branches could provide, I believe that a valuable statement of the agricultural industry's needs could be prepared. Some branches might want to go further and suggest ways and means of achieving objectives.

To illustrate the kind of statement I envisage, one might look to the East Anglian Branch to discuss some of the questions on soil cultivations I have already mentioned. The conclusions from these discussions could pinpoint trends in the adoption of new cultivation equipment, shown in detail where further information is needed and suggest ways in which it might be obtained. The possibility of utilising existing resources to provide this information would be considered, and suggestions put forward for the provision of new resources where necessary.

Similarly, the West Midlands Branch might well make a special study of orchard fruit mechanisation needs, and one of the northern or western branches might tackle the data problems being met in the development of mechanised forage feeding systems. There is no doubt in my mind that several branches, by tackling the problems most applicable to their local conditions, could provide sound guidance on how to meet their most important information needs. Overlapping work would be no disadvantage, although this could be avoided by consultation between branches, and co-ordination of the overall programme of discussion.

The Extent of the Institution's Role

If anyone doubts the Institution's ability to exert a worthwhile influence, he should consider the recent work of the East Anglian Branch in producing a guide to the writing of instruction books on agricultural machines, as well as the studies that preceded the setting up of the National College of Agricultural Engineering.

Some Branches would not be in a position to deal with more than a limited part of the subject, but the work as a whole could be comprehensive. It should embrace the provision of information in *EEC* countries, and might consider possible methods of abstracting results which could be of direct value here. Account should be taken of survey-type studies of the kind carried out by *ADAS*, and of any limited possibilities of recording information when a large number of machines are demonstrated at work on a single site.

I believe that the studies which I have suggested are particularly appropriate in the first place to Institution branches, and especially to those which are interested in alternatives to the usual type of meeting. I envisage that it might be possible for some branches to have had discussion meetings and have assembled some useful written material by the end of 1972; and that Council would then

BUILDINGS AND EQUIPMENT
FOR THE STORAGE OF POTATOES AND OTHER VEGETABLE CROPS

Storage Behaviour and Requirements of Crops and Their Influence on Storage Parameters*

by W. G. Burton BSc DSc(Leeds) MA(Cantab.)†

Summary

VEGETABLES are living and survive only between definite environmental limits; within these they respond to their environment in many ways—the effect of storage temperature upon the sugar content of potatoes is described as an example. Respiration rate varies with commodity, available oxygen and temperature. Rates quoted here, in air at 10°, range from 4 mg CO_2/kg h (maincrop potatoes) to 110 mg/kg h (calabrese). The rate is often approximately doubled for each 10° rise in temperature, but there are exceptions. Reducing oxygen to 3 per cent reduces CO_2 output to 40-80 per cent that in air. The rate of water loss from a commodity is proportional to the ambient water *VPD.* Absolute values depend on the commodity. Rates quoted, in per cent original weight lost per hour per mb water *VPD,* range from 0·0002 (onion) to 0·3 (lettuce). Maximum permissible percentage water loss, before a commodity becomes unsaleable, ranges from about 5 (lettuce, runner beans) to 10 (storing beetroot, potatoes). The variable properties of commodities influence the characteristics and management of stores—insulation, wall strength, ventilation, etc. The potato is used as an example to illustrate this.

Introduction

Vegetables differ from many other stored commodities in being living organisms. During the growing season they have increased in size and in their content of dry matter as a result of the absorption of water and of a host of reactions incorporating, into hundreds of more or less complex substances, carbon and oxygen from atmospheric carbon dioxide, and nitrogen, phosphorous, hydrogen and many other elements from mineral salts and water in the soil. The resultant carbohydrates, proteins and other substances, once synthesised, are not static but are perpetually undergoing further reactions including breakdown and re-synthesis. The net result, however, during growth, is an increase in the amount of material in the organism, which we could regard as an increase in internal or intrinsic energy as the result of absorption and transformation of energy from the sunlight. There are other groups of reactions occurring simultaneously with the above and collectively known as respiration, by which this intrinsic energy is on balance reduced, the loss appearing as heat, although a small proportion of the energy donated by various reactions in the process is re-allocated in the system and enables energy demanding syntheses to occur in the absence of an external source of energy. During growth, however, the incorporation of energy from sunlight exceeds its loss in respiration.

Broadly speaking, the nature of most of the individual reactions occurring in different plants is the same or similar, but the individual rate and the balance between them may differ considerably in a way characteristic of the particular plant species, with the result that the composition of the dry matter, its rate of turnover, and its distribution in the plant also differ. In the leafy vegetables, the whole of the net synthesis is incorporated in the leaves and in a stem and root system adequate to

* *Presented at the Spring National Meeting of the Institution of Agricultural Engineers at the Essex Institute of Agriculture, Writtle, Chelmsford, on 28 March 1972.*

† *Deputy Director and Head of Plant Division, ARC Food Research Institute, Norwich. President, European Association for Potato Research.*

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consider how to proceed. I should make it clear that I do *not* envisage that the Institution as such would be concerned with carrying out any scheme or schemes that might result. The responsibility for ensuring that any necessary information is provided clearly rests with the Ministry of Agriculture, which seems likely in future to exercise more influence than in the recent past over any work of this general nature.

It is perhaps worth recalling that the Royal Agricultural Society of England formerly played an important part in machinery trials; so the part that the comparable *DLG* in Western Germany plays today could perhaps usefully receive special attention.

I commend this study of objectives and of possible ways and means to the Institution's branches, in the belief that it would be one of the most worthwhile tasks that the Institution has tackled.

support them mechanically and absorb and transport the mineral salts necessary for growth. In some other plants, after a certain stage of development has been reached, much of the synthesised material may be translocated from the foliage, where it is produced, to developing storage organs where it accumulates. These storage organs are of course living, just as the foliage is living, but in general have a lower rate of metabolism than has the foliage. They have, in fact, evolved as organs which, after the death of the foliage, can survive independently and grow to produce a plant again. The period of independent survival could be short, if in the particular habitat regrowth was immediately possible or it could be a period of months, for instance over winter or over a dry period, prior to conditions becoming again favourable for growth. A low rate of metabolism is one form of adaptation involved in this evolution—were it not for this the food reserves necessary for re-growth in spring might well be frittered away in respiration long before they were needed. There is also a modification of longer-lived over-wintering foliage which aids survival. This takes the form of a shortening of the axis resulting in densely packed leaves surrounding the growing point and young inflorescence. The biochemical factors involved in the production of this modification, known as a bud, may be similar to those involved in, for example, the cessation of stolen elongation during the formation of a potato tuber. The result from the interactions between an environment which changes during the year in its characteristics of day-length, temperature, water supply, etc., and a plant which has altered biochemically, as well as in more obvious ways, throughout growth, in response to its past environment. A storage organ invariably either bears buds itself or includes a bud-bearing part of the parent plant. It can survive and grows again as an individual and is thus completely self-sufficient. A bud, on the other hand, survives and grows again only if attached to its parent plant and root system, or to a storage organ —in fact to a supply of nutrients.

Types of Commodity

Vegetable crops thus fall broadly into three categories—storage organs, which are naturally adapted to survive as individuals, often for a period of a few months; foliage and inflorescences, which are usually ephemeral; and foliage which is modified to survive conditions unfavourable for growth when still attached to the parent plant. The first and third of these, particularly the first, have the greatest inbuilt capacity for surviving storage, but this inbuilt capacity has evolved in respect of certain specific environmental conditions. Potatoes, for example, evolved in the tropics at altitudes up to about 4,500 m—in a climate which, for the most part, varies from warm temperate to cool temperate with moderate rainfall and night frosts. We can expect their tubers to survive and remain viable in the environment provided by the soil under such conditions. We need not expect them to survive in an environment widely different from this.

A further point needs to be mentioned in connection with foliage. Its function in the plant is photosynthetic. This means that the chlorophyll-containing cells in which photosynthesis occurs must receive adequate light and a supply of carbon dioxide. In a photosynthetic organ, cells which are not receiving light represent a loss to the system, in that they will be respiring, but not sythesising, and thus the most efficient shape for a photosynthetic organ, which assures the maximum illumination for the maximum number of cells, is either a thin lamina or a needle. Leaves have thus, by a process of mutation and elimination, evolved in this direction. To ensure a supply of carbon dioxide, the surface of the leaf must be permeable to gaseous diffusion, this permeability being provided by means of numerous pores in the surface, capable of opening and closing, known as stomata. Rates of photosyntheses vary, but an indication of the magnitude of diffusion is provided by the rate estimated for the lower surface of potato leaves of about 2 g CO_2 (roughly 1 litre) /m^2 surface/h at 20°C (Burton, 1966). Assuming 0·03 per cent CO_2 in the atmosphere, the maximum gradient activating this diffusion is about 30 Newtons/m^2, the rate of diffusion being thus about 33 cm^3/N/h. Permeability to the physical diffusion of one gas involves permeability to another of comparable molecular magnitude. Water molecules can diffuse more rapidly than can those of carbon dioxide and we could expect them to diffuse at a rate of about 46 cm^3/N/h from a leaf into which CO_2 could diffuse at 33 cm^3/N/h (Burton, 1966). Ability to photosynthesise at a rapid rate thus carries with it the liability to lose water at a rapid rate, and, by their very function on the plant, leaves are difficult material to store. Water loss is the most serious form of loss during storage—other than loss by disease—and will be discussed in more detail below.

Vegetable Structure

A vegetable consists of many million microscopic cells of which the majority have cellulose walls and contain protoplasm, which is the seat of all metabolic activity, resulting from the presence of very many potential reactants and of enzymes, largely protein in nature, capable of catalysing a very great number of the reactions which these reactants could undergo. That not all potential reactions are proceeding is due to the balance and control introduced by the relative concentrations and affinities of the reacting substances and by the lipoprotein membranes surrounding centres of reactivity. Very young cells are completely filled with protoplasm and its inclusions. In old cells it may merely line the wall, the rest of the cell volume being filled with an aqueous solution of substances excreted into it from the protoplasm as products or by-products of its activity. Each cell is completely permeated by water, which also permeates the areas of contact between cells. There can thus be diffusion of water throughout the whole organism, this is apart from the movement of water in the specialised water conducting system of the plant, a consideration of which is irrelevant to the present discussion. Nor is it necessary, in this context, to describe other specialised tissues and cells, merely noting that a vegetable organ is far from being microscopically homogeneous.

A plant is aerated, very efficiently, by interconnected air spaces, which in dense tissues may consist merely of small gaps between cells, mainly at the corners—as in a potato tuber; but in other tissues may be comparable in volume to the cells themselves. These spaces connect with the outside air by the stomata, in the case of a green leaf, or by other pores known as lenticels, incapable of opening and closing, in other cases—as, for example, in the potato tuber. Diffusion of gas through these spaces provides the oxygen used in aerobic respiration and the carbon dioxide used in the photosynthesis and voids to the outside air any gases or vapours of which the partial pressure in the spaces exceeds that in the outside air. This is normally so in the case of water vapour.

Water Loss

Because the cells, including their cell walls and protoplasm, are completely permeated by water, the spaces between them are very nearly saturated with water vapour. The water vapour pressure in the spaces must in fact be rather less than that of a free water surface, otherwise evaporation from cell wall to space could not occur, but the extent of this reduction, except when water stress develops, is probably slight. The equilibrium water vapour pressure is not necessarily calculable from the composition of the cell sap because the selective operation of the protoplasmic membranes could, and probably does, result in the aqueous solution permeating the cell walls, and which determines the water vapour pressure in the intercellular space, being of different composition from that inside the cell. For the purpose of discussing water loss, therefore, we probably do not introduce a large error by taking the water vapour pressure in the air spaces in the plant as being the same as that of a free water surface at the same temperature as the plant.

The rate of diffusion of water vapour from a given area of a plant is directly proportional to the water vapour pressure gradient from just inside the pores in its surface—taken, as discussed above, as approximating to the water vapour pressure of air saturated at plant temperature—to just outside the pores. The water vapour pressure just outside the pores is that of the ambient air, modified by local humidification resulting from diffusion from the plant. If air movement over the plant surface is rapid this local humidification resulting from diffusion from the plant. If air movement over the plant surface is rapid this local humidification is slight, and the water vapour pressure outside the pores is similar to that of the bulk of the ambient air.

The saturated water vapour pressure in air at temperature encountered in the storage of plant material is given in Table 1. On the basis of the discussion above we should be justified in taking the internal water vapour pressure of all fresh plant material to be as given in Table 1.

That the actual rate of water loss from plant material is less than that from a free water surface of equal area, exposed to the same water vapour pressure deficit, is due to the resistance introduced into the diffusion path by the outer integument of the plant. In many cases this integument may be almost completely impermeable to the diffusion of water except through the pores in its surface, and the rate of diffusion thus depends upon the number and spacing of the pores—the relationship with number being, incidentally, non-linear and variable because of interference between external diffusion gradients—upon their individual sizes, and upon the lengths of the diffusion paths through them. In other cases the integument between the pores may itself be to some extent permeable to water, and evaporation may therefore occur from its outer surface. It is thus possible for different types of plant surface to differ very considerably in the resistance which they introduce into the diffusion path. Individuals of the same species can differ, perhaps as a result of differences in growing conditions leading to differences in the structure of the outer integument and in the morphology of the plant. We can, however, determine average values for the rate of water loss from different types of stored vegetables, which give some indication of what to expect under various storage conditions. These average values are influenced not only by the fine structure of the plant discussed above, but by gross morphology. The degree of exposure of leaf surface to the ambient air may, for instance, differ—as for example in the series of decreasing exposure from spinach, through cos lettuce, hearted lettuce and brussels sprout and dense winter-storing cabbage. Where there is overlap of leaves, the air into which sheltered surfaces are evaporating no longer has the characteristics of the outside air but is humidified to an extent depending upon the degree of air movement over these sheltered surfaces. In a cabbage, for example, the air surrounding all except the peripheral leaves is still and humid. Water vapour cannot be swept away by mass air movement, but must diffuse by a long convoluted diffusion path to the outside air and its rate of loss is thus very considerably reduced.

Storage Potential

The nature of various vegetable materials, and the storage characteristics we might expect to be

Table 1

Pressure in millibars of the water vapour contained in saturated air (1 mb = 100 N/m^2)

Temp °C	0	1	2	3	4	5	6	7	8	9
0	6·08	6·53	7·01	7·53	8·07	8·65	9·27	9·93	10·63	11·37
10	12·16	12·99	13·87	14·81	15·81	16·86	17·97	19·15	20·39	21·70
20	23·09	24·56	26·11	27·74	29·46	31·28	33·19	35·21	37·33	39·56

Table 2

Nature and Natural Storage Characteristics of Some Vegetable Crops

Commodity	*Nature*	*Natural life-span in state acceptable for consumption*	*Natural potential for storage under ambient conditions after harvest*
Asparagus	Tip of young rapidly growing shoot	Very brief (c. 1 or possibly 2 days)	As in previous column
Beetroot	Storage organ — swollen root and stem	Some months in the ground in mild (Mediterranean) winters	As in previous column (note: "in the ground")
Broccoli, sprouting broccoli and cauliflower	Inflorescence — flower buds and stalks	Brief (c. 1 week)	As in previous column
Brussels sprout	Foliage — enlarged axillary bud	Several weeks under cool conditions	Less than previous column because of removal from water supply
Cabbage	Foliage — enlarged terminal bud	Several weeks under cool conditions	As above
Cabbage (winter storing)	Foliage — enlarged terminal bud	Several months under mild winter conditions	As in previous column, although outer leaves wilt and die
Carrot	Storage organ — swollen root	Some months in the ground in mild (Asiatic) winters	As in previous column (note: "in the ground")
Celery	Foliage — leaf stalks	Some months in mild winter conditions	Brief because of removal from water supply
Kale	Foliage	Several weeks (but a succession of leaves)	As above
Kohlrabi	Storage organ — swollen stem	Several weeks	As in previous column
Leek	Foliage	Several months throughout the winter	Comparatively brief because of removal from water supply
Lettuce	Foliage	Several days in the summer	Brief because of removal from water supply
Onion and shallot	Storage organ — swollen leaf bases	Some months under dry (Asiatic) conditions	As in previous column (note: "dry")
Parsnip	Storage organ — swollen root	Some months in the ground in mild (European) winters	As in previous column (note: "in the ground")
Potato	Storage organ — swollen end of underground stem	Some months in the ground in mild (S. American) winters	As in previous column (note: " in the ground")
Spinach beet	Foliage	A few weeks	Very brief because of removal from water supply
Turnip	Storage organ — swollen upper part of root and lower part of stem	A few weeks	As in previous column
Swede turnips	Storage organ — swollen upper part of root and lower part of stem	Some months in the ground in mild (European) winters	As in previous column (note: "in the ground")

associated with these, are given in Table 2. It should be noted, however, that these characteristics, in-built as it were during thousands of years of evolution in a particular habitat, may have been modified by human selection during centuries of cultivation. A storage organ may have evolved as a means of survival and become adapted to that end. Man, however, has selected on the basis, not of suitability for survival, but of palatability or other attributes he thought desirable, and may in the process have selected types not particularly suited to survive. He may also, inadvertently or of design, be wishing to store under conditions far removed from those for which a storage organ is adapted.

Biochemical Change During Storage

Within the conditions necessary for survival, vegetables, like all living organisms, respond to changes in the environment by changes in their metabolism.

As was stated earlier, hundreds of biochemical reactions are perpetually occurring in the protoplasm. To a very large extent these are interconnected. For example, accumulation of the products of one reaction can profoundly influence the rate or course of one or a number of other reactions, which in turn influence yet other reactions, and so on. In a growing plant the result of the reactions occurring is a more or less rapid synthesis of plant material—of structural material such as cellulose, of more protoplasm with its content of protein, nucleic acids and lipids, of storage reserves such as starch. As the plant grows there are tendencies for soil nutrient supply to be overstrained, for metabolic products to accumulate in varying forms, and for the structure of the plant to become, as a whole, photosynthetically less efficient. The environment also changes. The response of the plant varies with the species, but in general it results in a gradual decrease in the rate of metabolism of the organs with which we are concerned and in the eventual establishment of a state of near balance between synthesis and breakdown—at which stage we can regard the organ as 'mature'—followed by a period of decline, and eventually by death.

We harvest the vegetable at various stages of maturity. In several cases it may be mature and in a state where no rapid change is occurring—cabbage, for example, or a maincrop potato; in other cases, well exemplified by asparagus tips, the vegetable is immature and very labile and can in a matter of hours have changed markedly—asparagus develops lignified strands very rapidly and is then unusable. In any case, when the organism is harvested its metabolism continues rapidly or slowly, as the case may be, either on the same general course as before harvest, or perhaps deflected into other channels depending upon the response to the storage environment as compared to the environment before harvest. This continuing metabolism results in changes in composition and, since quality and nutritive value depend upon composition, in changes in these attributes. In time, it will result in senescence and death. Storage conditions must be designed to retard the chemical and physical changes which have adverse effects upon quality and to encourage those which have beneficial effects. It should be stressed that it is only a question of retarding or encouraging. It is quite impossible to completely stop change in living material. Death is inevitable. Also it should be stressed that the complexity of the inter-relationship between metabolic reactions is such that the effect of a change in storage conditions cannot necessarily be predicted, though we can make an intelligent guess. For example, a reduction in temperature might be expected in general to reduce the rates of reactions and thus delay senescence; while, if we regard respiration as an index of activity, and thus of the rate of deterioration, it might be beneficial to attempt to reduce respiration not only by lowering the temperature but by decreasing a reactant—oxygen—or increasing a product—carbon dioxide. Such lines of attack have shown positive results but, as stated above, the effect of a change in storage conditions cannot necessarily be predicted. This can be illustrated by the effect upon the rate of respiration of potatoes of lowering the storage temperature.

Experiments, often short-term, on the respiration of plant material have in many cases shown the overall rate of the process, in terms of carbohydrate respired or CO_2 released, to have a Q_{10} of 2. That is, over the range of temperature at which the material can survive and respond normally, say, 0-30°C, a 10° rise in temperature leads to a doubling of the rate of respiration. Published figures exist relating to the potato tuber, in which the rate of respiration during storage at 0° is assumed to be half, and that at 20° to be double, that measured at 10°C. This is approximately true immediately after placing at these temperatures, but nothing could be further from the truth after a few weeks at 0°. The overall rate of respiration may be limited by the rate at which a certain reactant can be combined enzymically into the respiratory cycle, this depending upon both the concentration of the reactant and the temperature. Lowering the temperature from 10° to 0° may halve the rate of combination provided the concentration of the reactant remains the same. In fact, however, lowering the temperature also influences the rates of hundreds of other reactions in the tuber, as a result of which marked changes in composition occur, including a great increase in the concentration of the reactant feeding into the respiratory cycle. The net result is that after a few weeks at 0°C a potato tuber may be respiring appreciably faster then it was at 10°C (see for example, Burton *et al*, 1955).

Fragility

Another property of living material must always be taken into account, and that is its fragility. Some indication of the anatomical structure of vegetables was given above. It is obvious that a structure consisting largely of millions of minute cellulose envelopes attached to each other, and each distended by the aqueous solution within its protoplasmic lining, may have considerable strength to oppose deformation by normal stresses—usual wind pressures for example. On the other hand, shearing forces or excessive pressure, particularly in the form of impact against hard surfaces, could clearly cause the rupture of some of the cells and of their protoplasmic membranes. If this occurs, the reactions in the ruptured cells are no longer controlled and held in check by the functioning of the selectively permeable membranes of the protoplasm; there is free play for the reaction of any reactive substance with any other through the mediation of any relevant enzyme system. As a result we may get the reactions which normally occur in the intact cell proceeding more rapidly, but we may also get many other reactions proceeding, some of which may have adverse effects upon quality. Melanin formation is an example. In the potato tuber, for instance, an o-diphenol: oxidoreductase, characterised by Abukhama and Woolhouse (1966), may act as one of the terminal oxidases in repiration and catalyse first the hydroxylation of tyrosine to 3, 4-dihydroxyphenylalamine and then the oxidation of this to phenylalamine-3, 4-quinone. In damaged cells the quinone is metabolised further, by a sequence of reactions, eventually to the black pigment melanin, one of the intermediate products being the red 2-carboxy-2, 3-dihydroindole-5, 6-quinone. This reddening and finally blackening of the surface of a peeled or cut potato is familiar. It can also occur in superficially intact tubers as a result of localised breakage of cells, caused by impact or pressure, and in this form is a serious problem under the name of internal bruising or black spot. Similar aberrant reactions can lead to discoloration of damaged leaves or of the cut or broken stems of harvested leafy crops. The fragility of plant cells can also be a liability in another respect, in that the exudate from broken cells can be a good medium for the proliferation of bacterial and fungal rots.

Necessary Information

It will have become clear from the foregoing that, before we can begin an intelligent appraisal of the possibilities for the storage of any vegetable crop, we need to know several facts about it.

1. How great are the losses if the commodity is stored for the required time exposed to ordinary ambient conditions, or the conditions obtainable in a simple shed or building? This indicates if there is in fact any storage problem.
2. What is the likely selling price of the commodity after storage? Taken in conjunction with the answer to (1) this tells us whether storage is worthwhile in any case and what we can justifiably spend in improving the storage.
3. What is its natural potential for storage—is it a storage organ or is it more ephemeral? This should indicate whether storage for a long time by simple means is a likelihood or whether, by contrast, storage is likely to involve considerable sophistication and expense.
4. What are its mechanical properties? These will greatly influence the bulk in which it can be stored and the methods by which it should be handled.
5. What is the packing density of the commodity in the form in which it is wished to store it (i.e. allowing for the packaging) ? This obviously is of prime importance in deciding the size of the building.
6. If bulk storage is possible, what is the angle of repose of the bulked commodity? This, in conjunction with the answer to (5), determines the necessary strength of the retaining walls.
7. What normally terminates its useful storage life—is it water loss and associated wilting; is it chemical and physiological change such as lignification or sprout growth or leaf senescence; is it rotting by disease organisms? The answer to this gives an indication of the type of change in storage conditions which is likely to have the greatest effect in prolonging storage life.
8. What are the limits of temperature, atmospheric composition, etc., within which the commodity can survive? These clearly must not be overstepped. They provide information for calculating the absolute minimum insulation in any locality and, in conjunction with the answer to (12) below, the minimum provision for ventilation.
9. How does the commodity respond, within the above limits, to changes in temperature and atmospheric composition?
10. What is the optimum temperature for the commodity from two points of view—extending storage life as an organism and retaining quality as a food? Survival and maintenance of quality are not necessarily synonymous. The potato tuber, for example, can be stored for a very long time at 2°C but is then too sweet to be acceptable.
11. How serious are divergencies from these optima? If the optima differ appreciably the practical storage temperature may have to be a compromise between them. It is therefore necessary to know how much weight should be given to the respective temperatures. There is also an economic argument. It may be foolish to strive hard, and expensively, to maintain a temperature of precisely x°, when the commodity would be scarcely less acceptable at, say, x $\pm$ 5°.
12. What is the rate of respiration, and associated heat production, of the commodity at the temperature in which we are interested? This provides information necessary for determining the minimum provision for ventilation (see [8] above). It also tells us how rapidly the commodity must be ventilated, with various air/commodity temperature differentials, to maintain it at a given temperature. It also, in conjunction with the answers to (13) below and (8), (10) and (11) above, determines the bulk in which the commodity can acceptably or safely be stored with a given rate of ventilation with air of given temperature.
13. What resistance does the commodity offer to air flow? This clearly, in conjunction with a knowledge of the desirable rate of ventilation (12 above), determines the characteristics of the ventilation system.
14. Is rapid cooling from field temperature to optimum holding temperature necessary or desirable? In the case of some ephemeral commodities a few hours at a high temperature may represent a waste of a high proportion of the potential storage life. In the case of storage organs this is unlikely.
15. What are the thermodynamic properties of the commodity—packaged for storage—such as specific heat, thermal conductivity and heat transfer to or from an air stream? A knowledge of these properties is essential if, at any stage in the storage procedure, the commodity must be cooled or warmed.
16. If rapid cooling from field temperature is necessary or desirable, is the commodity amenable to forms of cooling other than by air stream—vacuum cooling for instance? If removal of field heat is important it must be an integral part of the storage procedure and the means of cooling must be the most effi-

cient, taking full account of both technical and economic factors.

17. What is the rate of water loss from the commodity into air of given water vapour pressure deficit? This determines, for example, the effect of rate of ventilation on water loss and the extent to which humidification of the ventilation on water loss and the extent to which humidification of the ventilating air is economically justifiable. If halving the *VPD* lowered loss from 10 per cent to 5 per cent it could be very well worthwhile, but if it merely lowered loss from 2 per cent to 1 per cent the gain might be less than the cost—depending, among other things, on the selling price. The answer to this question also, incidentally, indicates whether vacuum cooling is technically feasible.
18. Can we exploit, at an economic cost, any response of the crop to changes in the environment other than its temperature and humidity—oxygen or carbon dioxide or ethylene concentration for instance? Reduced oxygen and increased carbon dioxide can markedly increase the storage life or, for example, some varieties of apple, but such changes are not a universal panacea; concentrations which are beneficial for one commodity may be harmful for another.
19. What pathogens attack the commodity and how do environmental conditions influence attack? Environmental conditions can influence the growth and development of pathogens; the balance between different pathogens, with possible synergistic or antagonistic effects; and the development by the commodity of physical and biochemical resistance to attack.
20. Are there any particular storage hazards which we should be aware of and what are they? A case in point is the danger associated with including a wet load of potatoes in a bulk store.

If we can answer the above twenty questions, or such of these as are relevant, with respect to the commodity we wish to store, then we are in a position, not only to store it with some degree of confidence, but to assess the pros and cons of any change in our normal storage practice suggested by changed circumstances—by, for example, change in the degree of mechanisation of harvesting and other operations; a changed pattern of marketing; a desire to exploit a particular demand at a particular time; and so on.

Although I have enumerated these questions one by one, it is difficult, except in the more precise technical ones, to be equally specific about the answers. Even in such cases, for many commodities the information does not, as yet, exist. So the answers I will be able to present may be scanty.

There is a commercial storage problem of varying type and seriousness with every commodity listed in Table 2. Broadly speaking, storage of the ephemeral vegetable material is not possible under ordinary ambient conditions, and even the storage organs present difficulties, due in some measure to the fact that we are not content with the natural storage life of a few months, but wish to extend it to suit our requirements rather than those of the plant. Also, it must be remembered that plant organs which have evolved to be capable of survival for some weeks or months have evolved to survive in a viable form, not to be palatable or even edible. In a bud, such as a cabbage, all that is necessary for the plant is that the growing point should be sufficiently protected to be capable of growth when conditions are right: the decrepitude of the leaves surrounding it is of no importance.

The answer to question 2 is very important but it will not be discussed here. It is an economic and not a technical matter. The answer is absolutely basic to all considerations of storage, taken in the broad context of steady employment of labour, maintaining supplies to the market and the goodwill of the market, growing a certain acreage of certain crops because of requirements of the rotation, etc.

Question 3 is answered for a number of crops in Table 2.

The answer to question 4 must be subjective rather than given in any measurable quantities. In general, storage organs have more mechanical strength than have the more ephemeral parts of plants. Leaves are readily damaged; the flower buds of cauliflower, for instance, even more so. On these grounds it is not possible to store such material in bulk, whereas root crops, potatoes and onions can all be stored in quantity and limitation of the size of the bulk may result more from factors such as the heat production of the crop than from its fragility. Nevertheless, though the storage organs, at least when turgid, may withstand the pressures involved in being piled to considerable heights (3-4 m is usual with potatoes and on occasion they have been stored to as much as 7 m) they cannot withstand being roughly handled in the process. Breaks, cuts, splits and abrasions are common, and have tended to become more so with increased mechanization of handling. Sometimes they introduce a storage hazard—they are a means of ingress of pathogens —but in any case they represent a loss of quality. One can quote the findings of Twiss and Jones (1965), based on a survey of 68 farms in 1961-2: "It was found that almost one third of potatoes leaving the farm had suffered some mechanical damage deeper than could be removed by single peeling: a further one third exhibited less severe flesh wounds, which could be thus removed. . . 12 per cent of all tubers exhibited internal discoloration when cut at the end of the storage period." They did not distinguish between the different forms of internal discoloration but a proportion was presumably caused by pressure or impact damage.

Winter-storing cabbage may present an apparent contradiction to the distinction above, between leaves and storage organs. The contradiction is more apparent then real, in that the outer leaves may well be damaged if the cabbages are stored in bulk, but they are trimmed before sale.

It is obviously desirable that the mechanical properties of vegetable crops should be quantified in some meaningful way; the difficulty lies in making it meaningful. We are concerned not so much with the point at which, say, the structure shears, but with the point at which deformation is such that an unacceptable degree of cell breakage occurs. This depends not only on the type of material but upon its conditions and the details of its chemical composition. Take the potato tuber as an example. Firm potatoes stored 3 m high suffer no pressure damage in the main bulk, though where pressure is greater, where they impinge on hard edges as, for example, on the ridges and slats of ducts, damage can occur. If the tubers are wilted then damage often occurs in the bulk because wilted tubers can be deformed, and if deformation is excessive a certain amount of cell breakage occurs. Impact damage is much less in tubers with a high content of potassium (Ophuis *et al*, 1958; Vertregt, 1968) and the higher the handling temperature the less it is, over the range 1-30°C and particularly 3-18°C (Wiant *et al*, 1951; Ophuis *et al*, 1958). It is difficult therefore to give a simple quantified description of the mechanical properties of a potato tuber, and the same applies even more to commodities of less regular shape and less uniform structure.

The remaining questions enumerated above are more capable of precise answers. The answers may not be known, but that is because the necessary experimental work has not yet been done, rather than because of the nature of the questions. An attempt will be made below to answer some of them. Table 3 gives an indication of the main faults terminating storage; Table 4, optimum storage temperature; Table 5, rates of respiration and heat production; Table 6, water loss; Table 7, tolerable limits of water loss, which indicate the seriousness or otherwise of the information in Table 6. These tables are based for the most part on work at the Food Research Institute by Robinson and Browne, not yet published in detail, but in course of publication.

Table 3

Examples of Types of Deterioration Terminating Useful Storage Life

Commodity	*Storage terminated by:*
Asparagus	Lignification, wilting at butt end, loss of flavour.
Beans (runner)	Lignification, wilting, rotting.
Beetroot (bunching)	Wilting.
Beetroot (storing)	Wilting, regrowth, rotting.
Brussels sprouts	Wilting, leaf senescence (yellowing), rotting, off flavours and odours.
Carrots (storing)	Wilting, rotting, regrowth.
Cabbage (winter storing)	Leaf abscission, regrowth (bursting), wilting, rotting.
Cauliflower and Calabrese	Yellowing or opening of florets, wilting, rotting, discoloured butts.
Lettuce (cabbage)	Wilting, bruising (discoloration), rotting, discoloured.
Onions (bulb)	Rotting, growth.
Potatoes	Rotting, wilting, sprout growth.
Spinach (true)	Wilting, rotting.

Table 4

Suggested Optimum Storage Temperatures

Commodity	*Temperature °C*	*Commodity*	*Temperature °C*
Asparagus	2	Cucumber	5
Beans (runner)	5	Lettuce	2
Beetroot (storing)	2	Marrow	5
Brussels sprouts	2	Onions	2
Cabbage (winter storing)	2	Potatoes (ware and canning)	4
Carrots (storing)	2	Potatoes (other processing) (short-term)	10
Cauliflower and Calabrese	2	(long-term)	7
Celery	2	Spinach	2

Table 5

Rates of Carbon Dioxide Production (Approximate Average Values in mg/kg h) and Associated Heat Production

Storage atmosphere:	Air			3 per cent 97 per cent N_2[1]		
Temperature °C:	0[1]	10	20	0	10	20
Commodity			*CO_2 production*			
Asparagus	27	58	120	26	40	50
Beans (scarlet runner)	20	35	90	15	25	45
Beetroot (salad bunching)	11	20	40	7	14	32
Cabbage (January King)	6	26	57	6	17	27
Cabbage (winter storing)	3	8	20	3	5	11
Calabrese	48	110	260	—	70	130
Carrots (storing)	11	20	34	—	—	—
Celery	7	12	33	5	9	22
Lettuce (summer cabbage)	18	27	85	16	19	55
Onions (bulb)	3	7	8	2	4	4
Potatoes (mature maincrop, see footnote [1])	2	4	8	2	3	6
Spinach (true)	20	50	130	—	—	80
Turnips (bunching)	15	30	52	10	19	39

The above figures for CO_2 production multiplied by 2·5, give heat production in kilocalories per metric ton, and multiplied by 10 give it in Btu per ton.

[1] *These figures give the immediate response to these conditions. In commodities capable of prolonged storage some adjustment in rate may occur. This is particularly noticeable in the potato in air at 0°C, the respiration of which may rise to about 8 mg/kg h, during the course of a month, because of sweetening.*

Table 6

Rate of Water Loss From Stored Commodities

Commodity	*Water loss (per cent/hour per mb water VPD)*
Asparagus	0·15
Beans (scarlet runner)	Related to size and maturity; e.g. 0·05 in c. 50 g beans, 0·15 in c. 10 g beans.
Beetroot (bunching)	0·3 falling in the course of days to 0·085 as the leaves dry out.
Beetroot (storing)	0·065
Brussels sprouts	0·1 falling in course of days to 0·08 as outer leaves dry out.
Carrots (Nantes 20)	0·08
Lettuce (cabbage, 'Hilda')	0·3
Onions (bulb)	0·0002
Peppers (green)	0·025
Potatoes (mature maincrop)	0·001

Table 7

Approximate Maximum Permissible Water Loss

Commodity	*per cent loss*	*Commodity*	*per cent loss*
Asparagus	8	Carrots	8
Beans (runner)	5	Celery	6
Beetroot (bunching)	5	Lettuce	5
Beetroot (storing)	10	Potatoes	10
Brussels sprouts	6		

Information Relating to the Potato

Because the total value of the potato crop is much greater than that of any crop with which we are concerned, and because it is the crop of which the physical aspects of storage have been most studied an attempt is made in Table 8 to bring together in summarised form the answers, relating to the potato, to all twenty questions.

Table 8

Information Relevant to the Storage of Mature Maincrop Potatoes

Question (See text for full formulation of questions)	*Answers in skeleton form*
1. Losses?	Very rough average for healthy maincrop potatoes with no sprout suppression: stored for 1 month, 1 per cent; 2 months, 1·5 per cent; 3 months, 2 per cent; 4 months, 2·5 per cent; 5 months, 4 per cent; 6 months, 6 per cent; 7 months, 8·5 per cent; 8 months, 12 per cent; 9 months, 16 per cent.
2. Selling price?	Varies with season. Average 1964-70 (£/ton)[1]: 'Reds' Oct. 17·2, Nov. 18·3, Dec. 18·9, Jan. 19·7, Feb. 19·15, Mar. 20·75, Apr. 24·95, May 23·8. 'Whites' Oct. 14·15, Nov. 14·9, Dec. 15·3, Jan. 16·3, Feb. 15·85, Mar. 17·7, Apr. 21·05, May 21·6. Potatoes for processing are usually supplied under contract at a negotiated price.
3. Natural storage potential?	Several months.
4. Mechanical properties?	Bulk storage to 7 m without pressure damage has been claimed. This depends on variety and condition and absence of sharp edges. Heights of 3-4 m usual. Wilted tubers show pressure damage at these heights. Subject to impact injury causing internal discoloration.
5. Packing density?	Depends on shape, size, etc. About 1·4 m³/ton for oval or kidney ware[3].
6. Angle or repose?	30-40°, depending on shape, amount of earth, etc. 35° is fair average[3].
7. What terminates storage?	Of healthy potatoes, sprout growth, wilting and changes in composition, such as sweetening, which accompany senescence. In practice, disease also plays a considerable part (see 19).
8. Environmental limits?	Freezing point −1° to −2°C. Internal breakdown at 35°C and above. Safe limits 0°-20°C. Oxygen > 1 per cent CO_2 < 10 per cent.
9. Response to environment?	Usually dormant when harvested but after some weeks become capable of growth. Over the range 0-25°C the dormant period is usually shorter the higher the temperature. Non-dormant buds do not grow at 2°C, very slowly at 4° and more rapidly the higher the temperature up to c. 20°C. Reducing O_2 concentration shortens dormancy and stimulates growth, down to optimum of c. 5 per cent O_2 below which there is reduction in growth and inhibition at 1 per cent O_2. Increased CO_2 stimulates sprout growth up to c. 7 per cent above which there is a reduction. Inhibition at 15 per cent but this is beyond the safe limits. Sugar content shows inverse relationship with storage temperature below 10°C. Typical total amounts of sugar would be: 10°, 0·2-0·3 per cent; 8°, 0·3-0·5 per cent; 6°, 0·5-0·8 per cent; 4°, 1-1·5 per cent; 2°, 1·5-2 per cent; 0°, 4-5 per cent. Low oxygen (1-3 per cent) temporarily (1-2 months) prevents low temperature sweetening. Exposure to light loads to synthesis of chlorophyll and of the poisonous alkaloid solanine, mainly at the periphery of the tuber.
10. Optimum storage tempertures?	For survival c. 2°C. For ware market c. 4°C for long storage; c. 10°C short term. For most processing requirements c. 7-8° for long storage; c. 10° short term. In every case harvesting wounds must first be be healed by allowing a temperature of > 10° for 2 weeks or so.
11. Acceptable range of temperature?	For processing little deviation from optimum is permissible for long term storage. Short term 10-15°. For the ware market holding in the range 2-15° is adequate. See (10) foı wound healing.
12. Rates of respiration and production?	Respiration at minimum of c. 1·5 ml CO_2/kg/h evolved, or O_2 taken in, at 5°C. Rises slowly to c. 2·5 ml at 15°C and more rapidly to c. 6 ml at 25°. Below 5°C rises rapidly to c. 4 ml at 0°C (long term storage) (2 ml/kg/h = c. 10 kilocalories/ton/h = c. 40 Btu/ton/h)[4].
13. Resistance to air flow?	$P = KV^{1.8}$ where P = pressure in mm W.G. per m, V = approach velocity, m/h; $K = 5{\cdot}3 \times 10^{-5}$ for clean potatoes $7{\cdot}7 \times 10^{-4}$ for potatoes with 20 per cent earth. Sprouting increases resistance up to fourfold.[4]
14. Is rapid cooling necessary?	No.
15. Thermodynamic properties?	Specific heat 0·86 cal/g/°C; thermal conductivity of tuber flesh 5 cal/cm²h under gradient of 1°C/cm; potential heat transfer to air 0·43 cal/cm²/h/°C diff at 20 cm/s (proportional to $V^{0.31}$)[5]. Actual heat transfer in practice limited by heat capacity of air involved.

Table 8 Cont'd.

Question	*Answers in skeleton form*
16. Amenable to various cooling methods?	Not to vacuum cooling.
17. Rate of water loss?	About 0·01 mg/cm²/h/millibar water *VPD* (= about 0·17 per cent per week per millibar *VPD*). Perhaps four times as much first week after harvest. Every 1 per cent by weight of sprouts increases potential loss by about 0·08 per cent/week/millibar *VPD*[4].
18. Any exploitable responses?	Various chemicals (e.g. chloro-iso-propylphenyl-carbomate, maleic hydrazide and 3-5-5 trimethylhexen-1-01) prevent sprouting. Sprouting can be stimulated by a mixture of the vapours of ethylene chlorhydrin, ethylene dichloride and carbon tetra-chloride.
19. Attack by pathogens?	Disease is by far the most serious source of storage loss. National average annual loss probably about 500,000 tons (c. 7-8 per cent). A survey on 41 farms in 1961-2 showed average rotting on those farms to be 15 per cent in that year, ranging from 2 to 68 per cent[6]. Main storage diseases are blight *(Phytophthora infestans)*, pink rot *(Phytophthora erythroseptica)*, dry rot (*Fusarium* spp.) gangrene (*phoma solanicola*), watery wound rot (*Pythium spp.*), skin spot (*Cospora pustulans*) and bacterial rots (probably mainly *Erwinia carotovora*). In general, rotting is slower at low temperatures (<5°C) provided harvesting wounds have healed. Wet tubers are particularly liable to bacterial rotting.
20. Storage hazards?	Rotting of diseased tubers; massive bacterial rotting because of wet tubers (rain or condensation); local heating because of earth cones; frost damage; greening if exposed to light; low temperature sweetening below 10°C, more particularly below 5°C.

[1]Callis (1970); [2]Messer *et al* (1970); [3]Wilson and Twiss (1960); [4]Burton (1966); [5]Mann (1963) unpublished work; [6]Twiss and Jones (1965).

It will be appreciated that information summarised in tabular form may give an impression of dogmatic finality. This is not the intention. Vegetables are individuals, and the figures given are averages which give some guidance as to the orders of magnitude. Take for example the answer to question 12 in Table 8. It can be deduced from this that the rate of carbon dioxide evolution from a sample of potatoes at 10° would be about 2 ml/kg/h. This is a reasonable average value as a basis for calculation provided it is understood that figures as low as 1 ml and as high as 5 ml/kg/h can be encountered in individual and apparently normal tubers. Similarly for water loss (question 17); 0·01 mg/cm²/h/mb *VPD* is a good average value, but the range is at least 0·008-0·012 mg. All the answers in Table 8 are subject to such qualification and amplification.

As an example of the use which can be made of the information given in the table, deductions based on it are given below for mature maincrop potatoes, numbers in parentheses being those of the relevant questions and answers in the table.

The natural storage potential of potatoes is such that by providing suitable conditions we might reasonably contemplate spreading the storage season until the beginning of the following harvest—say 9 months (3). If we prevent sprout growth, either by temperature control (9) or chemically (18), have no losses from disease (but see 19), and maintain a water *VPD* of no more than 1 mb, our losses by the end of the season will be of the order of 7 per cent (17). Taking this into account, the average appreciation in value per ton put into store may be of the order of £4 by the end of the season (2). This must cover the annual charge of the building, all management, and running costs, and loss of interest on the monetary value of the crop. Any loss by disease or sprouting or any increase in *VPD*, and hence in evaporation, erodes this £4. Rotting to the extent of the national average estimated by Twiss and Jones for the season 1961/2 (19) would reduce it to about £1·50, barely sufficient to cover the annual charge of a simple building, let alone equip and run it. The designer of a potato store must therefore be very cost-conscious.

Potatoes can be stored both in small units and in bulk, certainly to a height of 3-4 m (4). If bulk storage is employed the walls of the building must be sufficiently strong to resist the thrust, which can be calculated to be about 150 kg/m²/m height of stack (5 and 6, using Rankine's formula—see e.g. Wilson and Twiss, 1960). The degree of insulation depends upon local weather conditions and upon the heat production (12) and acceptable range of temperature (8, 10, 11). For ordinary ware storage in most of Great Britain a heat transmittance of less than 1 k cal./m² h °C difference between inside and outside surfaces of the wall is usually adequate, but for potatoes for processing, transmittance of less than 0·5 k cal. is preferable.

From the heat production (12), thermodynamic properties (15), resistance to air flow (13) and the known thermal properties of air, it is possible to calculate equilibrium temperatures in stacks of any size to an accuracy of about ±0·5°C for mathematical treatment see Burton *et al*, 1955). The range of temperature in a stack 3 m high ventilated only by natural convection could be expected to be 5-6°C. This is a sufficiently small range for ordinary ware potatoes but may frequently be unacceptable for potatoes for processing (11). If these are stored in bulk, forced draught ventilation is desirable. From the heat production (12), thermodynamic properties (15) and known thermal properties of air it can be calculated that continuous ventilation at a rate of about 30 m³/ton/h will normally maintain a temperature gradient of no more than 1°C. The overall rate of cooling of a stack can also be calculated. Calculation of the rate of cooling at any point in a stack is more complex. An approximation to the time taken to cool different parts of a stack to little above inlet air temperature is given by the relationship derived by Ophuis and Hesen (1957) from the cooling curves calculated by Businger (1954):

$$t = \frac{40250}{5400 + 3V_a} + \frac{2130x}{V_a}$$

were t is the time in hours, x the distance in metres from the bottom of the stack and V_a the approach velocity of the ventilating air in m/h.

Ventilation, both forced and convective, reduces local humidification and permits the continued evaporation of water from the tubers. The rate of this evaporation is proportional to the difference between the water vapour pressure of the tubers (which depends upon their temperature, as in Table 1) and that of the air. A high rate of continuous ventilation, by maintaining a small temperature gradient, may actually lead to a lower rate of water loss than a low rate of ventilation which permits a large temperature gradient. This has been considered in more detail elsewhere (Burton, 1966), but for our present purpose it can be shown from the figures for heat production (12), thermodynamic properties (15), water loss (17) and the known thermodynamic properties and water holding capacity of air, that rapid forced ventilation, as compared with natural convection, has little effect upon water loss except in the first week after harvest, or when the potatoes have sprouted, or if an appreciable temperature gradient has previously been allowed to develop.

Clearly, diseased tubers should so far as possible be excluded from store, but in practice some rotting is inevitable (19). Massive bacterial rotting, which is much more serious than any other form, is not inevitable but usually follows some malpractice such as not allowing wounds to heal (10, 18), putting wet potatoes into store (20) or permitting the potatoes to become wet (20). To avoid encouraging the spread of rotting, storage after wound healing (10) should be at the lowest temperature (19) which considerations of quality (10, 11) permit.

Potatoes for consumption should not be exposed to light (20), nor can they be held under conditions under which oxygen is completely depleted (8) or excessive carbon dioxide has accumulated (8).

So much for potatoes, though much more could be said. Perhaps I can summarise very briefly what I have been trying to indicate at some length above. Plant material is living. There are therefore environmental limits outside which it cannot survive, and if these are overstepped storage is at an end. Within these limits the commodities respond to their environment in many ways which may or may not affect their quality for a particular purpose. They also respire, lose water and are liable to attack by pathogens. Storage conditions can be adjusted to minimise loss of weight and retain or even, in some cases, where chemical composition can be changed beneficially, enhance quality. It is possible that requirements for retention of weight and of quality or of different aspects of quality could be in conflict. In such a case the optimum compromise must be sought—but always with due regard to cost.

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The Shape and Size of Storage Units in Relation to Performance[†]

by H. J. M. Messer BSc ARICS*, R. T. Lindsay BSc MIAgrE**, M. A. Neale NDAgrE**

Abstract

THE temperature and dimensional parameters may be determined for an unventilated bulk store by using an equation formulated by Burton *et al*, provided the resistance of the crop to air flow, its metabolic heat production and packing density are known. The results of an experiment are given which show that potatoes stored in a box behave as a small unventilated bulk store. Consequently the same equation may be used.

The effects of the shape and size of storage units in relation to building size and cost, handling, damage and weight loss are discussed and it is suggested that storing root vegetables in boxes may require less labour and provide a simpler means of controlling temperature than storage in bulk but that these benefits are achieved at a higher capital cost.

The different methods of cooling vegetables are discussed together with the results of a survey that indicated a very low rate of heat removal from these crops in existing stores. It is concluded that there are insufficient data available to determine the best container for cooling and storing leaf vegetables.

Introduction

When crops are stored, the grower anticipates that he will, later, receive extra cash that will more than pay for the cost of storage. However, the extra return obtained after storage is often small and so the cost of the storage buildings and their equipment must be as low as possible consistent with their ability to prevent deterioration of the crop. Broadly speaking, storage buildings may be classified into those that are designed, with their equipment, for the storage of crops harvested in the autumn — principally roots destined for long-term storage and those designed for summer harvested crops—principally leafy vegetables destined for short-term storage. To keep costs to a minimum, winter storage buildings need be no more than frost-proof and to have some means of ventilating the crop with ambient air; but because ambient temperatures are comparatively high in the summer, buildings for storing leafy vegetables must be well insulated to exclude heat and have some means of artificially cooling the crops. These factors make such buildings comparatively costly.

One important function of a storage building for potatoes and vegetables is the removal of heat from the crop. The speed at which it is removed is a function of the initial temperature of the crop, its rate of heat production, the difference in temperature between the crop and the cooling air, and the resistance of the crop and its container to the passage of air. The initial temperature of the crop and its rate of heat production at any given temperature are beyond the control of the grower but the air temperature in the store and the resistance of the crop to air flow, which is related to the shape and size of the storage unit, are within his control.

A second important function of a store, especially where pod and leaf vegetables are concerned, is the control of moisture loss from the crops. For crops as harvested, this is most dependent on the vapour pressure deficiency of the store atmosphere although the type of storage unit can have a marked effect on moisture retention when plastics film or other containers impermeable to water vapour are used. In such cases, the rate at which heat can be transferred from the crop by conduction or convection within the container to the store air outside becomes critical. So once again the type of storage unit and its resistance to air flow have an important bearing on the performance of the store.

Storage of Roots in Winter

The effect of the shape and size of the storage unit on temperature

Storage in Bulk

The rates of heat production of root crops at different temperatures are well documented[1] but it is only with potatoes that an intensive examination has been made of the relationship between the temperatures of the stack and the store air. Because they respire and so produce heat the temperature of an unventilated stack of potatoes will rise above that of the surrounding air and the heat produced is normally sufficient to cause convective air currents which remove the heat as fast as it is produced. Burton *et al*[2] has described this state as one of thermodynamic equilibrium and as long as this state continues healthy potatoes can be stored with-

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* *Head of Crop Storage Section, Farm Buildings Department, NIAE.*

** *Farm Buildings Department, NIAE.*

out undue loss but if the air flow is curtailed for example by a high proportion of soil in the stack, by the presence of sprouts, or because at high temperatures the temperature differential between the stack and the air may be insufficient to cause sufficent air movement to remove the metabolic heat then an unventilated stack can overheat.

The following equation (modified from Burton *et al*) provides a means of determining the maximum height a given sample of potatoes may be stored without overheating:

$$(T_p - T_a)^{2\cdot8} = \frac{K}{8\cdot94 \times 10^{-4}} \left[\frac{Qh}{D}\right]^{1\cdot8}$$

when T_p = average temperature of the potatoes (°C)
T_a = average temperature of the ambient air (°C)
K = coefficient of resistance to air flow of the potatoes
Q = metabolic heat (K cal/t/h)
h = height of stack (m)
D = packing density (m^3/t)

The amount of heat loss by conduction is small in comparison with the amount of metabolic heat produced by a large bulk of potatoes stored in a frost proof building and so heat lost by conduction has been ignored in this equation which may be used for other root vegetables provided the correct values for K, Q and D are used. The values for Q are available from the literature and those for D can be determined by direct measurement on the spot. The value of K will vary with species and the condition of a particular sample and has been determined at $7\cdot7 \times 10^{-5}$ for clean potatoes as lifted and 2×10^{-4} for a sample of potatoes with 20 per cent earth[3 4]. Work is in progress in the Farm Buildings Department of the National Institute of Agricultural Engineering to determine the K value for other vegetable crops.

After the field heat has been removed the temperature of an unventilated stack of potatoes or other roots depends largely on their rate of heat production and on the smallest dimension of the stack[2]. The least dimension is usually the height and calculations using values for the temperature conditions usually found in the United Kingdom indicates that potatoes should not be stacked more than 3 m high in an unventilated stack and if the value of K is substantially increased, by the presence of soil for example then the height of the stack must be lowered to prevent overheating.

The risk of overheating can be avoided and the safe height of the stack increased by installing air ducts under the crop and so permitting ventilation with ambient air either with or without fans. When fans are used it is usual in the United Kingdom to ventilate potatoes with 70 m^3 of air/t/h although higher rates of ventilation are used on the Continent. The increase in the height of the stack achieved by the use of fans can reduce the cost of buildings per ton stored. It is also interesting to note that the Potato Marketing Board Survey of 1958[5] stated that where potatoes were stored in buildings the depth rarely exceeded 6 ft and was never more than 10 ft. It is not surprising, therefore, to find ducts were used only in 14 per cent of the indoor stores and that fans and ducts were used in only 2 per cent of them. By 1968 a similar survey[6] reported that 33 per cent of the buildings had ventilation ducts and 12 per cent ducts and fans indicating a considerable increase in the amount of potatoes stored in ventilated buildings especially as the percentage of the national crop stored in buildings had risen from 50 to 70 in the same period.

The increase in the use of buildings equipped with ducts and fans is partially due to an increase in the number of growers with a larger acreage of potatoes but such buildings are also an insurance against storage losses as wet potatoes can be dried or warm potatoes cooled by ventilation.

Summary—Bulk Storage

The length and breadth of bulk storage units for roots have small effect on the cooling of the crop which is dependent upon its heat production and its resistance to air flow through the smallest dimension of the stack which is usually the height. The maximum height to which roots may be safely stacked without ventilation can be determined from the equation devised by Burton *et al* for potatoes and if it is desired to stack roots higher than this then means must be provided for supplying air to the bottom of the stack. In theory, there is no limit to the height to which roots may be stacked provided a fan is used to supply the air but the cost of the load bearing walls required probably limits the stack height to about 4-5 m at the present time. Further, any greater height than this would probably result in crop losses through pressure damage at the base of the stack.

Storage in Pallet Boxes

In recent years there has been an increase in the use of pallet boxes for storing potatoes and the Potato Marketing Board Survey in 1968[6] of main crop potatoes indicated that about 3 per cent of the national crop was stored in this way. Potatoes in boxes require a space of about $1\cdot4$ m^3/t and the boxes of potatoes in a store occupy about $2\cdot4$ m^3/t, the difference between these two volumes being mainly air spaces between the boxes. It follows that when a box store is ventilated most of the air will not pass through the potatoes till the resistance caused by the speed of the air and by the nature of the other surfaces of the boxes equals the resistance of the potatoes to air flowing through them.

It has been suggested that a box of potatoes behaves as a miniature unventilated bulk store[7] and therefore heat will be taken away from the potatoes by convective air currents within the boxes until such time as the potatoes and the store air reach a state of thermodynamic equilibrium. Because the dimensions of the boxes are relatively small, the temperature of the potatoes will rapidly approach that of the store air and it has been calculated that they will have a maximum temperature of 1-2°C above that of the store air[7]. Although information on temperatures in bulk stores is extensive, little has been published on temperatures in commercial box stores. In recent years Farm Buildings Department of the National Institute of Agricultural Engineering has recorded temperatures in a commercial box store[8] and it is proposed to consider some of the results obtained before discussing and comparing the use of buildings for bulk box storage.

Design of the Experimental Box Store

The store was 36·5 × 15 × 4·6 m to eaves and was designed to hold about 700 tons of potatoes in pallet boxes at a temperature of 10°C and not less than 7°C. The roof, of asbestos cement sheeting, was supported by timber stanchions. The space between the stanchions was infilled with a cavity wall 1 m high above which a timber frame supported timber boarding on the outside and flat asbestos sheeting on the inside. Fibreglass insulation, 50 mm thick was placed between the inner and outer skins of the wall and polythene film between the asbestos cement sheeting and the fibreglass. The roof was underdrawn at eaves level by flat asbestos sheeting, fixed to timber joists, with polythene film between the sheeting and the joists, and the whole upper surface covered with 75 mm of fibreglass. A 4·6 m wide door was provided near the middle of one wall with timber panels placed behind it to increase its insulating properties.

Four manually controlled fans were placed above the ceiling in a chamber at one end of the store. Air was drawn into the chamber through openings in one gable end blown into the store through an opening in the ceiling stretching from one side to the other. After it had travelled along the length of the store, the air passed through another opening in the ceiling and so into a small chamber where it was exhausted through the openings in the other gable end. A duct of 1·5 m² sectional area was built in the roof space above the ceiling and air could be recirculated by shutting the openings in the gable ends and by opening doors at each end of the duct. The duct was vapour proofed and insulated in the same manner as the ceiling.

Each of the four fans were a 475 mm single stage aerofoil type giving 13,500 m³ of air/h against a head of 40 mm swg. The fans were reversible, and two were each fitted with a 4 kW heater in two elements of 2 kW. Thus the store could be provided with a total of 54,000 m³ of air/h and a total of 8 kW of heat. In addition two sprout suppressant dispensers with fans were installed.

The potatoes were stored in 1 and 0·5t slatted pallet-based boxes and stacked in columns each consisting of three 1 ton boxes and 1 half ton box, the latter being placed between the second and top box. The boxes were stacked in two blocks either side of the door and each block was divided by a 0·6 m wide central passageway. Two blocks were five boxes wide, 12 deep and three and a half high and two blocks were four wide, ten deep and three and a half high.

Temperature

The temperatures in the boxes of potatoes and of the store and ambient air were recorded on a potentiometric recorder using 80 copper constantan thermocouples. The air temperatures were recorded every two hours and the temperatures in the boxes every 12 hours and the calculated difference between the temperatures in various positions have been used in this report.

Results

The mean temperature gradient of the store air from inlet to outlet at ceiling level was about 1·3°C the maximum difference being 3·3°C. There was seldom any difference in the temperature across the centre of the store and on the few occasions when there was the variation did not exceed 1°C. The mean temperature gradient from floor to ceiling was also about 1·3°C. (range 0 to 3°C). Thus it can be said that under the standard of management practised the store provided good air distribution and maintained, by commercial standards, an adequately constant air temperature.

The mean difference in temperature between the store air and the potatoes was 1°C in the first year and 2·3°C in the second year. In that year the autumn was so wet that an excessive amount of soil adhered to the potatoes and the boxes became so heavy they were not filled to capacity. When they were riddled after storage they were found to be about half filled with soil. From Burton's equation it can be calculated that the K value for the potatoes was $2{\cdot}8 \times 10^{-5}$ in the first year and $1{\cdot}1 \times 10^{-4}$ in the second year which compares with the values of $7{\cdot}7 \times 10^{-5}$ and 2×10^{-4} previously mentioned.

If the potatoes stored in the second year had been stored in bulk to a depth of 3 m the store air would need to have been 5·1°C cooler than the potatoes before a state of thermodynamic equilibrium could have been reached. If the temperature of the store air was 5°C then the average temperature of the potatoes would be 10·1°C before reaching equilibrium and the maximum temperature in the stack would be 15°C. It can be argued that under adverse storage conditions potatoes will be kept with less risk of overheating in small units than they will be in an unventilated or even a ventilated stack where soil may prevent adequate cooling in certain areas.

Variation in the Temperature of the Potatoes in the Boxes

The temperature of potatoes in a box in the centre of a block of boxes was on average about 1°C warmer than those on the outside of the block, the maximum difference being 2·5°C. The mean difference in the temperature of the potatoes in boxes placed on the upwind and downwind edges of the block between the air inlet and the centre of the store was also about 1°C with a maximum of 5·5°C. The small temperature difference between the boxes of potatoes and the store air together with those within the block confirms the suggestion that the boxes behaved as miniature unventilated bulk stores.

Temperature Gradient in a Column of Boxes

Within a column of boxes placed in the centre of a block of boxes the temperature gradient of the potatoes was on average about 2°C from the bottom to the top box but only 0·8 and 0·5°C between the second and third (half ton box) and the bottom box. The temperature gradient between the bottom, second and top box was almost linearly related to height whilst the smaller temperature difference between the half ton box and the other boxes was doubtless due to the minimum dimensions of the half ton box being half that of the larger boxes.

Temperature Variation Within Boxes of Potatoes

The difference in the temperature was recorded in four positions in each of 15 boxes. It was assumed, for the purpose of the calculations, that the thermocouples in the centre of each box, was in the warmest position. The mean difference indicated that the potatoes at the lower front of the boxes were 1°C cooler than those at the centre and that those at the middle of the sides and at the centre of the backs were 0·5°C cooler than those in the centre. Further, the temperature of the potatoes at the sides and top were warmer than those in the centre on more occasions than the potatoes in the front of the box. Thus the potatoes on the side and top were more affected by the temperature of the store air and it is suggested that the design of the ventilation system and the method of stacking the boxes enabled air to pass more easily between the sides of the adjoining boxes and over their tops than between the front of one box and the back of the box in front of it.

The difference in temperature found at all levels within the columns of boxes and the temperature variation between different parts of a box were not sufficiently large to effect the storage of ware potatoes, nor if seed had been stored in a similar way would the increase in temperature necessarily produce sprouts in one part of the box that were unacceptably longer than those in other parts.

Weight Loss

The weight loss of the potatoes in 153 boxes weighed before and after storage was between 0·03 to 0·04 per cent/day, an amount that is no greater than would normally be expected in a bulk store. The actual weight loss varied from 2·4 to 15·0 per cent for storage periods of 149 to 262 days. These results compare with a loss of 0·022 to 0·039 per cent/day recorded in Sweden[9] where the actual weight loss varied from 2·9 to 9·6 per cent for storage periods of 141 to 208 days. Potatoes have a corky layer under their skin which impedes water loss; other root crops, particularly carrots, will lose water much more readily. However, water loss is a function of the vapour pressure deficiency of the air used for ventilation rather than a function of the size and shape of the storage unit.

Summary—Storage in Boxes

Potatoes stored in a slatted box behave like a miniature unventilated bulk store. The temperature of the produce rapidly approaches to within 1-2°C of that of the store air because the minimum dimensions of the box is relatively small and because the warm air can move out of the box through the four sides and top of the box.

Although adequate temperature control can be achieved in both bulk and box stores it is easier to achieve a desired temperature in a box than in a bulk store because the air need not be distributed so evenly throughout the store. It is sufficient to remove the warm air and introduce cool air and to allow the heat to pass from the potatoes to the store air by convection.

The effect of Size and Shape of Unit on the Building Size and Cost

Potatoes occupy 1·4 m^3/t[10] but when stored in boxes they occupy 2·4 m^3/t[11]. The floor area required in a store naturally depends on the height to which potatoes are stacked.

Table I
Size of store/t

Method of storage	*Space required in the store m^3/t*	*Floor area m^2/t*
Box-1 t capacity stacked three boxes high	2·4	0·7
Bulk—stacked 2·4 m high	1·4	0·6
Bulk—stacked 3·7 m high	1·4	0·4

It is generally accepted that it is cheaper to increase the volume of an agricultural building by increasing its height rather than its floor area. Thus the floor area required by box and bulk stores stacked 2·4 m high is the same and it is not until potatoes are stacked in bulk 3·5 m high that appreciable saving in building cost can be expected.

The cost of a box store can be reduced because it is unnecessary to build load bearing walls but it has been calculated that in a 450 t store the cost of the boxes was about three times the difference between the cost of load bearing and non-load bearing walls[11]. Thus the capital cost of storage in small units like 1 or 0·5 t boxes will exceed the cost of storage in bulk in temporary structures such as a "Dickie Pie" or in a permanent building.

The effect of Size and Shape of Unit on Handling

Although the rate of harvesting and transporting potatoes from the field to the store is outside the scope of this paper, it should be noted that harvesting by machine into boxes usually gives a lower output than handling in bulk, because of the need to discharge the potatoes into the comparatively narrow top of the box and to replace the full boxes on a harvester adapted to carry boxes[12]. When potatoes are hand picked the rate of lifting into boxes is about the same as lifting into trailers[13]. Furthermore, any difference between the rate of transporting potatoes in boxes or in bulk depends upon the capacity of the trailer.

Twenty tons/hour is quoted as a rate for loading both bulk and box stores[12], a capacity beyond that of lifting on most farms but less labour is required at a box store as there is no elevator to move or wooden ducts to install. The mean rate for filling a box store has been given as 2·4 man min/ton as opposed to 10 man min/ton for a bulk store[13], and with such a rapid loading and turn round rate it is possible for each tractor driver to unload his boxes and so dispense with a man at the stores.

Similarly the unloading from a box store is about 40 per cent faster than using a tractor with a bucket to unload a bulk store but both rates are normally greater than the output of the riddle. Less damage is caused to the potatoes when they are unloaded from boxes.

The Effect of Size and Shape of Unit Damage

There is little evidence on differences in total damage between bulk and box handling. A comparison at Sutton Bridge indicated a significant advantage for field filled boxes over bulk handling—60 per cent of the potatoes in the boxes were undamaged as opposed to 55 per cent in the bulk store[12].

Summary—Comparison of Box and Bulk Storage

Every storage system depends on the standard of management and the particular requirements of the farm on which it is used. To generalise is dangerous but the scoring system (A good to C poor) given in Table II may clarify the difference between storing potatoes in boxes or in bulk, and it is suggested that storing potatoes in boxes may require less labour and provide a simpler means of controlling temperatures than storage in bulk but that these benefits are achieved at a higher capital cost.

Table II
Comparison of box and bulk storage

Parameter	*Box*	*Bulk*
Rate of lifting	B	A
Loading into store	A	B
Control of temperature	A	B
Unloading from store	A	C
Damage	A	B
Cost of building	A	B
Cost of boxes or ducts	C	A

The Storage of Summer Harvested Crops

Introduction

The pattern of harvesting vegetables is changing. There is a trend towards growing crops in larger units on larger holdings where the grower often has associations with processors or supermarkets who usually require an agreed quantity of produce of a higher quality than that provided by the smaller grower. Furthermore, as the performance of varieties that mature evenly becomes more reliable the possibility of once over manual harvesting should result in more efficient and higher labour output compared with the present harvesting system. The development of mechanical harvesters has made possible once over vegetables harvesting at rates much higher than that achieved by hand, but harvesting machinery, unable to operate under as wide a range of conditions as hand workers, can be employed on fewer days in the year. The result is that in the immediate and in the long term future there will be an increasing need to store leafy vegetables, either to avoid flooding the market or to make it possible to fulfil contracts for the regular delivery of agreed quantities at all times. Although extensive work has been carried out at Ditton Laboratory[14] and in the United States[15] on the cooling of fruit, there is little information available on the cooling of leafy vegetables.

The storage life of vegetables can be extended by cooling them as quickly as possible to temperatures below 5°C after they have been harvested, and there are some indications that in the future, contracts for the supply of vegetables will require the vegetables to be cooled. Three methods can be used—vacuum cooling, hydro cooling or the passing of chilled air through the produce. With both vacuum and hydro cooling, the produce is cooled in as many minutes as it takes hours with air cooling[16 17]. However, a vacuum cooling plant is very expensive and consequently it is only practicable where there is a very large volume of produce to cool. At one co-operative in Holland, for example, 800,000 heads of lettuce are vacuum cooled per day[18]. With this method there is no limit to the shape or size of the unit that can be cooled, other than that determined by the cooling chamber, provided that there are holes in the containers for water vapour to escape from the produce. A large refrigeration plant is required for hydro cooling and there are serious problems in keeping the water clean and sterile. At the present time there would appear to be little demand for either of these two systems of cooling and even if such systems are used in the future the produce will have to be held in an air cooled store designed to remove the heat of respiration and the heat that leaks into the store.

The Effect of Size and Shape of Unit on Air Cooling Vegetables

A survey of commercial cold stores has shown that the rate of heat removal from a wide range of vegetables in a variety of containers was less than 1°C/h although on many occasions the temperature of the air returning to the cooling unit was only slightly above that at which it left[19]. Such a rate of cooling, which is much smaller than that required for efficient vegetable storage, is caused by the failure of the cooled air to circulate effectively through the produce in the store.

Most vegetable stores contain a cooling unit which exhausts cold air near the ceiling of the store and draws in the warm air at a lower level. There is no doubt that cooling rates would be faster if growers prevented air from short circuiting from inlet to outlet by using polythene film or plywood sheets to blank off the gaps between the containers of produce.

Most leafy vegetables must be stored in containers as they are liable to damage from crushing, although there are exceptions such as Dutch cabbage which can be stored in bulk.

Burton's equation can be used to determine the conditions under which the vegetables and the store air will reach thermodynamic equilibrium. For example, if it is assumed that when cooling spring cabbage

$$
\begin{aligned}
T_D - T_a &= 15°C \\
Q &= 145 \text{ kcal/t} \\
h &= 1 \text{m} \\
D &= 1{\cdot}5 \text{ m}^3/\text{t} \\
\text{then} \quad K &= 4{\cdot}6 \times 10^{-4} \text{ and if} \\
T_D - T_a &= 50°C \text{ and consequently} \\
Q &= 50 \text{ kcal/t}, \\
\text{then} \quad K &= 1{\cdot}5 \times 10^{-4}
\end{aligned}
$$

In these two examples, the effect of a smaller difference between the temperature of the produce and the cooling air is largely offset by the smaller heat production of the produce at the lower storage temperature. Further, the calculated value for K is similar to that of potatoes containing about 50 per cent soil.

Until data are available on the resistance of leafy vegetables to air flow, it is impossible to determine the size of the container in which they can be stored safely. It is probable, however, that some form of pre-cooling will be required possibly in a chamber designed to force air through the containers or, alternatively, by tipping the produce on to a moving belt or tray and cooling them before they are re-packed.

Summary—Units for Leaf Vegetable Storage

At the present time there are insufficient data available to determine the best size of container for cooling and storing leaf vegetables.

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Parameters for the Environmental Control of Crop Stores*

by D. I. Bartlett NDAgrE[†]

Summary

A SUGGESTED design procedure for controlled temperature stores is described. An indication of the way in which external design parameters may be selected and used is given.

Introduction

The optimum storage conditions for a range of products have been given. Also some indication of the range which is acceptable in practice. The store designer must now produce a store which meets these requirements at an economic price.

The probable returns as a result of storing a crop dictate the type of store that can be considered. Crops which have a long storage period and low value will generally only justify ventilated storage. Examples of these are: red beet, onions and potatoes. Refrigeration may be justified in some cases with these crops where they are to be kept beyond the end of the normal season. They may then attract much higher prices. Where crops to be stored have a short life and a high value, refrigerated storage can be justified. A short storage period means the store can be filled a number of times during a season. Short-lived crops usually show an improvement in quality if they can be kept cool. Examples of the crops which may benefit from refrigerated cool storage are lettuce, asparagus, runner beans and calabrese.

Ventilated Storage

The general aim of this storage method is to maintain the crop at the required storage temperature by selective ventilation with ambient air.

Selection of Fan Capacity

The success of a ventilated storage system depends on the control system, the size of the fan in relation to the quantity of produce and the ambient air temperature during the storage period. The control system must be able to identify:

a. When the stack temperature is above ambient.

b. When the stack has reached the required temperature.

c. When ambient air is too cold.

If this type of control is used, it is possible to derive a relationship between product temperature and fan capacity. To do this, it is necessary to use a large amount of meteorological data.

Fig. 1 shows this relationship for a building which was to be used for sprouting main crop potatoes. Calculations were based on March temperatures at Sprowston. The 'U' value for the structure was 1·14 W/m² °C (0·2 Btu/ft² °F/h). The building held 100 tons of seed contained in trays.

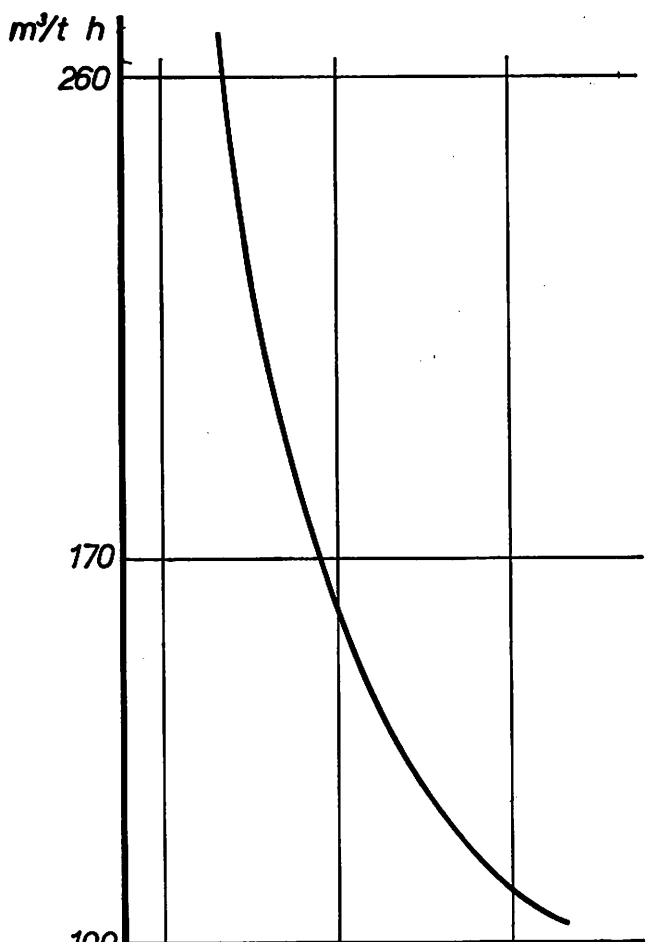


Fig. 1 Store temperature v fan capacity

¹ See Appendix.

* *Presented at the Spring National Meeting of the Institution of Agricultural Engineers at the Essex Institute of Agriculture, Writtle, Chelmsford, on 28 March 1972.*

† *National specialist in crop storage of ADAS, East Malling.*

It will be seen from Fig. 1 that a very high rate of ventilation must be used to keep the *average* store temperature below 3°C. It is calculated[1] that during the worst two years out of ten, there will only be 16 per cent of the month when temperatures are below 3·3°C. This compares with 29 per cent in five years out of ten. As a general rule it will not be possible to maintain an average storage temperature lower than the ambient temperature which is exceeded for 70 per cent of the time. As an illustration, using the above example, in five years out of ten it would be reasonable to expect to maintain a store temperature of 3·3°C (38°F). During the worst two years out of ten one would expect an average store temperature of 5·6°C (42°F). These figures can only be considered as guides but may provide a useful indication of the storage likely temperature.

The foregoing discussion is based on a store filled with trays. The resistance to air movement is relatively small. This resistance is under the control of the designer. (Typical system resistance will be 1,0 mb (0·4 in swg). Crops such as potatoes, onions and red beet are often stored in bulk. Ventilating air must pass through the stack and in doing so, will suffer a pressure drop. This pressure drop depends on stack height and air velocity. Stack height is determined by economic requirements and limited by the need to avoid damage to the crop. The pressure drop due to the ventilating air is therefore dependent on velocity. By the principle of conservation of energy—the pressure and velocity energy in the air entering the stack is very largely converted to heat within the stack. If the aim is to cool the crop it can be shown that very high ventilation rates will not be effective.

Fig. 2 shows 'Cooling efficiency' assuming a constant *LMTD*** between crop and air. It is based on the equation:

$$\eta = \frac{Q \text{ crop}}{Q \text{ total}}$$

η = efficiency
Q crop = heat removed from the crop $h_o = kV^{0.3}$)
Q total = heat rejected from complete system.

This curve is calculated for potatoes but will be similar for other crops with similar resistance.

A further practical consideration in selecting a fan capacity can be the rate of removal of the crop from the store. It may be that because of the need to use labour during the winter months or the need to provide a continuous supply of produce for sale, by the time that ambient air temperatures are rising there is only a small proportion of the crop left in the store. Under such circumstances the fan capacity per tonne of crop ventilated late in the season may be high thus improving the chances of keeping the average store temperature down. For large stores (1000 tonnes+) managed in this way, it can be an advantage to use two fans each providing half the duty. This gives flexibility at the end of the season and may help to avoid desiccation which might be caused by the use of ventilation rates in excess of 172/m³/t h (100 f³/min).

** *LMTD = log mean temperature difference 2°C (3·5°F).*

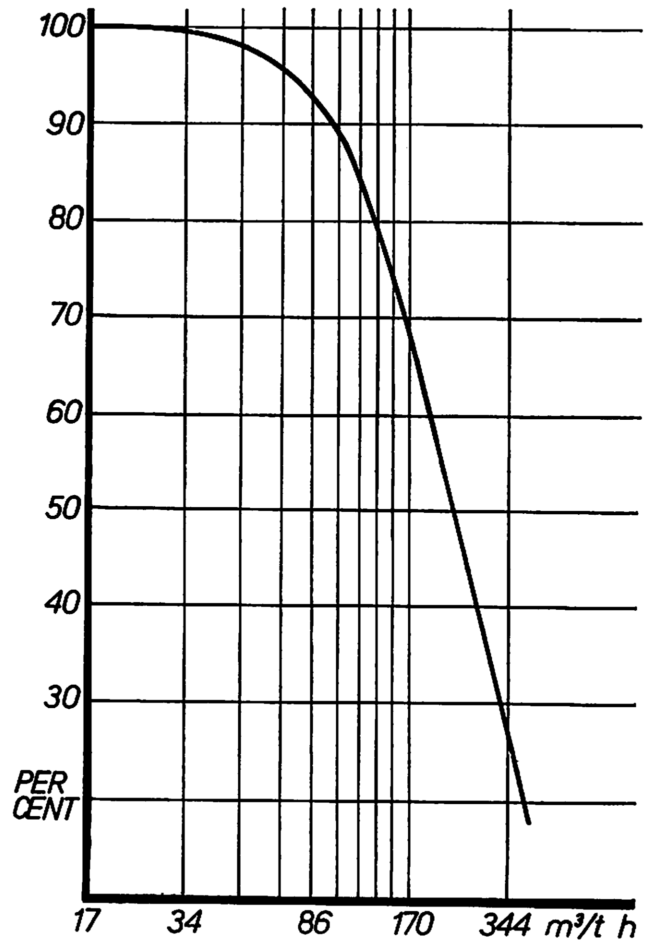


Fig. 2 Cooling efficiency

Table 1
Suggested Design Ventilation Rates

Crop	*m³t h*	*ft³/min/t*	**Density** *m³/t*	*ft³/t*	*øResistance K*
Potatoes	69	40	1·4-1·57	50-60	
Red beet	69-86	40-50	1·68	60	
Onions	172	100	1·96-2·80	70-100	0·14 to 0·4

ø The value quoted in the table K in the equation $P = kV^{1.8}$
P = pressure loss mb V velocity m/s (approach)

The ventilation rate which gives the best overall cooling efficiency is higher than the design figure quoted. It may be assumed that only part of the crop needs ventilation at one time and that 103-137 m³/t h (60 to 80 f³/min ton) can be given to potatoes and red beet, while for onions the rate must be 395 m³/t h (230 f³/min ton).

Ventilation rates for onions are based on the need to dry the crop quickly (70 to 100 hours). Temperature control is secondary to this requirement. During storage, onions pose different problems to most other crops. They require a dry cool atmosphere (70 per cent RH 0-2°C). These conditions of ambient air do not occur very often so the crop is normally held at a higher temperature (3-4°C) except where refrigeration is provided.

It is possible to illustrate the optimum ventilation rate for a stack of potatoes 3 m (10 ft) deep; this lies in the range 103-120 m³/t h (60-70 f³/m ton). Based on data from source[2], the sensible total heat ratio (*STHR*) for the ventilation process can be calculated. (Heat transfer is based on an *LMTD* of 2°C products of air).

The results are plotted in Fig. 3.

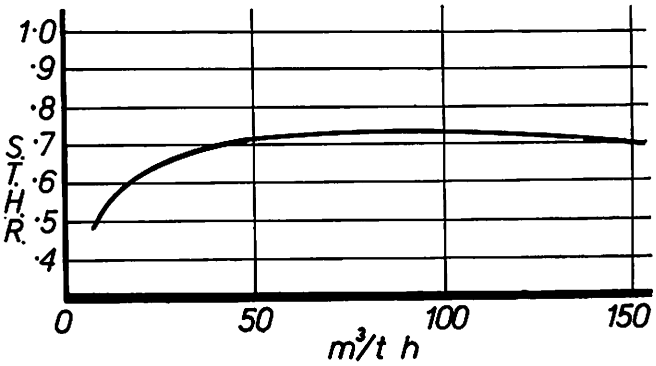


Fig. 3 Sensible total heat ratio (STHR) v Ventilation rate

Recirculation for Ventilated Stores

This has been shown[3] and stated in previous papers that, left to its own devices, a stack of produce will develop a temperature gradient which is balanced by convected flow of cooling air. This will mean that some parts of the stack are not at the correct temperature. It has been shown in practice that this gradient can be considerably reduced by recirculation of the store air.

Assuming no gains of heat other than by respiration the following recirculation rates can be suggested:—

Humidification

It is inevitable that water will be lost from the crop during cooling since there must be a temperature difference between the product and the cooling air. Even if the air entering a stack is saturated its vapour pressure must be below that of the produce[4] and hence vapour transfer will occur. The average *RH* in the *UK* is about 80 per cent. It tends to rise as temperature falls so during periods of low temperature, when cooling may be done, the *RH* is usually high. It is important that humidification, if it is done, is carried out efficiently. Droplets of water may be carried into the stack and wet it. These conditions may increase the incidence of rotting. Humidification may be desirable in red beet and carrot stores since these crops lose water more easily than potatoes, onions and storage cabbage. If humidification is used the equipment should have a maximum rating of 0·24 kg/tonne/h (0·52 lb/h/ton). (0·14 kg/tonne/h would probably be adequate) and it it would be desirable to fit an eliminator to prevent excessive carry-over of liquid water.

Great care must be exercised in the use of humidification if serious losses are not to occur.

The Application of Refrigeration to Bulk Stored Crops

The use of cool ambient air has been considered as a means of controlling product temperature. Depending on locality, it becomes increasingly difficult to maintain the crop temperature low enough. Based on the criteria outlined earlier in this paper, the probable product temperature that can be maintained at Terrington has been calculated.

Table 2

Crop	Δt across stack 1·6°C(3°F)		0·6°C(1·2°F)
Potatoes, Onions	8·6 m³/t h	(5 f³/min ton)	25·8 m³/t h (15 f³/min ton).
Red Beet, Carrots	32·7 m³/t h	(19 f³/min ton)	99·8 m³/t h (58* f³/min ton).

* *Recirculation rates above 20 f³/min ton will probably prove too expensive. Intermittent recirculation can be used successfully.*

The resistance to flow is very small so a low power fan is required (e.g. main fan run at low speed). Because the *TD* between the air and the crop is small, the *VPD* is also small so the evaporation of water from the crop will be slow.

If recirculation is done it must be regular. Recirculation applied to a stack which has been allowed to develop a temperature gradient can result in condensation on the lower layers of crop.

Recirculation in onion stores must be provided during the drying phase. This is necessary to prevent the *RH* of the drying air becoming too low. The crop may be dried at temperatures of 25 to 30°C and an RH of >60 per cent. Up to 80 per cent of the drying air may need to be recirculated depending on outside conditions.

[2] *EDA. Electrification Handbook No. 18 and Mann, G.—unpublished.*

[3] *Burton and Mann.*

Table 3

	Air Temperature Max.	*Min.*	*Mean Stack Temperature*
January	4·3	−2·4	−2·1°C
February	6·1	0·7	0·9
March	10·7	2·3	4·0
April	12·7	4·5	6·1
May	15·5	6·5	8·3
June	19·1	9·2	11·2*

* *No account taken of solar heat gain.*

From the above table it can be seen that to maintain a product temperature of 2°C beyond early March, mechanical cooling will be required. For long term potato storage refrigeration will be needed from about mid April. The figures used here are averages for four years at one location and are used as an illustration. Specific projects must be assessed

[4] *Burton.*

using long term information relating to the area in question[5].

The application of refrigeration in a *conventional* bulk store presents problems. This is particularly so if only a small proportion of the crop remains at the end of the season. Heat gains through the structure together with high air leakage rates tend to lead to disproportionately large refrigeration requirements in relation to the quantities of crop being held. If the store has been built with mechanical cooling in mind from the outset many of these problems can be overcome.

Calculation of Refrigeration Duty

The maximum duty is made up of the following components:—

1. Heat gain through the structure.
2. Heat gain by air leakage.
3. Heat evolved by crop respiration.
4. Electrical heat input (eg circulating fan).
5. Heat to be removed from the produce to cool it to storage temperature.

The calculation of individual components are based on the *IHVE* and *ASHRAE* guide books[6].

1. Heat gain through the structure. This heat gain may be considered as being made up of two parts: (a) Gain due to conduction from outside air to the store air and (b) Gain due to solar radiation.

Table 4 has been prepared to show the relative importance of solar heat gain. The table is based on the 'equivalent temperature'ø method described in the *ASHRAE* guide. The calculation has been done for a roof in full sun. A light structure has been assumed and so no lag or diminuition of heat flow occurs. The values quoted in the table are averages for one day. Much higher instantaneous *ET's* exist during the day but because of the thermal inertia of the stack the average is considered sufficiently accurate.

Table 4

Comparison of Steady State and Solar Heat Gain at 50° N

Month	*2% Design Temperature*	*Steady State*	*Equivalent TD*	*% Hours Sun*[7]
January	11·1	3·9	2·7	19
February	10·4	3·2	3·7	24
March	14·4	7·2	8·8	31
April	16·0	8·8	11·9	34
May	20·0	12·8	20·0	40
June	24·1	16·9	23·9	41

For stores which will operate up to the end of March it is suggested that the heat gain calculations are based on steady state methods. A design outside temperature which is exceded during 2 per cent of the design month should be satisfactory. (This may need to be raised to 1 per cent for small stores with low thermal inertia). From April onwards it becomes increasingly important to consider solar gains. Most solar heat gain occurs through the roof of a building both because it is normally light construction and because of its exposure. The walls are not so important because they may be of heavier construction and may be shaded from direct radiation. On this basis it is suggested that solar heat gain calculations are made for the roof and that steady state conditions are assumed to apply to the walls. A daily average of the instantaneous heat gains on the roof should be used.

In long term bulk storage the heat gain load is the largest component of the refrigeration duty. This is not so for cool stores which may be used for short term holding of produce. In these stores the cooling load assumes major importance.

2. Heat gains by air leakage. The following table shows the sort of infiltration rates that may be expected for average stores of various size.

Table 5

Volume m^3	*Volume* ft^3	*Air Changes/h* *Changes of Normal*	*Empty Short term*	*Volume/h Long term*
5·66	200	1·83	3·66	1·09
11·32	400	1·22	2·44	0·73
28·32	1,000	0·72	1·44	0·43
141·60	5,000	0·30	0·60	0·18
283·20	10,000	0·20	0·40	0·12
566·40	20,000	0·15	0·30	0·09
1133·00	40,000	0·10	0·20	0·06
2832·00	100·000	0·06	0·12	0·03

Table 5 is based on date obtained from the *ASHRAE* guide.

Having established the likely air infiltration rate the heat gain can be calculated using psychrometric tables. (Considerable errors may result from the assumption that the heat load is due to dry air especially in short term stores where air infiltration is high).

Appendix 2 is included to aid calculation. It shows the enthalpy change KJ/m^3 between outside ambient air at 80 per cent *RH* and store air at 92 per cent *RH*.

3. Heat evolved by respiration. Data on this has already been presented[8]. Maximum refrigeration demand usually occurs during pull down. At this time the crop is warmer and therefore evolves heat faster. It is suggested that the respiration rate used in calculations should be 1·1 times the mean of the loading and storage rates. This allows for the non linearity of the respiration/temperature characteristic.

4. Electrical heat input. The main input to be considered in this context is the circulating fan. I can be assumed that all the electrical energy input to the fan is converted to heat.

Fan capacities for bulk stores may be determined as a result of the need to make use of ambient air for cooling. A lower rate of circulation is generally sufficient where refrigeration is employed. It is suggested that the maximum enthalpy change across the

[5] *Monthly Weather Report.*

[6] *Institute of Heating and Ventilating Engineers Guide and American Society of Heating, Refrigeration and Air conditioning Engineers' Guide.*

ø *Q UA (TD_e). TD Equivalent temperature difference. Q = Total heat flow. U = Thermal transmittance. A = Area.*

[7] *Climate and the British Scene. Manley, G.*

[8] *Storage behaviour and requirements of crops and their influence on storage parameters. Burton, W. G.*

cooler should not exceed 4·65 kJ/kg (2 Btu/lb). The minimum enthalpy change will be limited by the increasing power required to drive the fan. A figure of 2·3 kJ/kg (1·0 Btu/lb) is suggested.

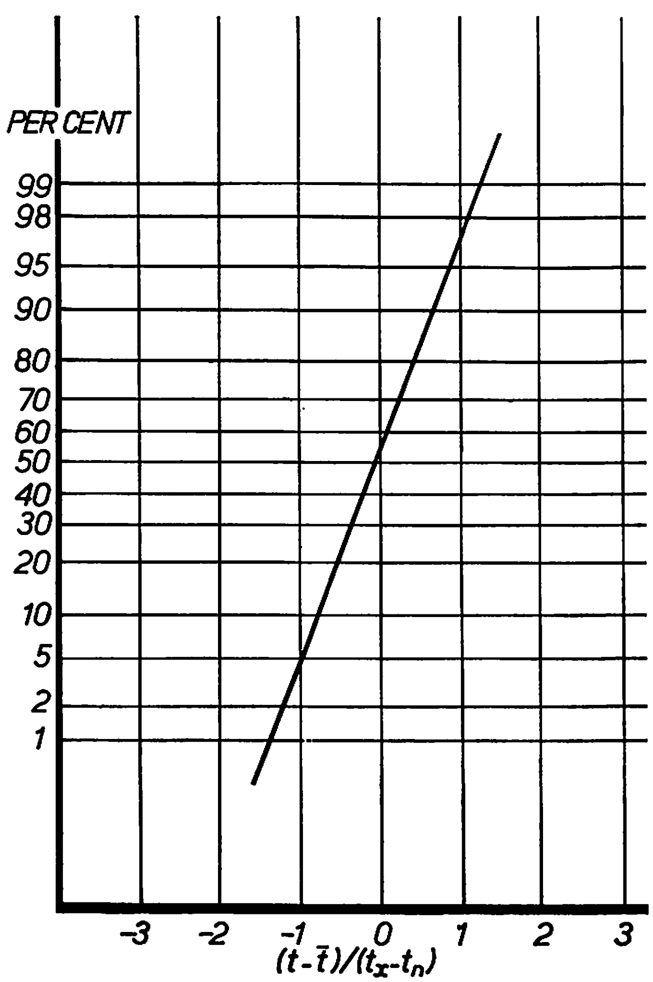
The fan capacity for normal cool stores is not so limited by system resistance. The important feature is to provide air speeds over the produce which will enable cooling to be completed in the time allowed. Typical circulation rates are 40 to 60 times the empty volume of the room per hour.

Heat input (W) is given by:—

$$W = \frac{99{\cdot}9\ P_{(T)}\ V}{\eta} \qquad \left\{ \text{/ imperial units} \quad \text{Btu/h} = \frac{V\ P_T\ 0{\cdot}4}{\eta} \right\}$$

W = watts input
$P_{(T)}$ = static + velocity pressure (mb)
V = volume of air displaced (m^3/s)
η = total fan efficiency (typically 0·65 axial fan)

5. Cooling load. This can represent the major component of the total refrigeration duty. (50 to 70 per cent). The size of the cooling load depends very greatly on the speed at which the temperature of the produce must be reduced. For example, it can be generally stated that crops which have a long storage period only require slow cooling. The maximum refrigeration requirement for these stores may be the 'holding' load at the end of storage. This is particularly so where, for example, potatoes are kept until the end of May.



Shellard and Sarson chart for March

To consider the other extreme, lettuce needs to be cooled to its storage temperature overnight. In addition to the need for large machine capacity there may be difficulties in transferring heat from the produce to the air stream. An earlier paper[9] mentions that the rate of cooling in commercial cool stores was <1°C/h. In order to comply with the requirement to cool to storage temperature overnight an average cooling rate of >1°C/h is needed.

A comprehensive study of the cooling of lettuce is reported by Ir T. van. Hiele[10]. He shows how by increasing the air speed over the produce, the cooling time is reduced. For example, a 'close' stacked pallet load of lettuce under room cooling conditions shows a half cooling time of 8·5 h while the same package subjected to an air speed of 3·5 m/s shows a half cooling time of 3·5 h. The first figure agrees with the findings of the *NIAE* referred to earlier.
The following table gives suggested design cooling times:—

Asparagus, Runner Beans, Lettuce, Spring cabbage	12 to 18 hours (overnight)
Cauliflowers, Sprouts	18 to 24 hours
Carrots	7 days
Beetroot, Cabbage (storing)	14 to 20 days
Potatoes, Onions (bulb)	3 to 6 weeks as conditions permit

[9] *The shape and size of storage units in relation to performance. Messer, H. J. M., Lindsay, R. T., and Neale, M. A.*

[10] *Verpakking en transport. Hiele, T. van. Sprenger Institute Annual Report 1967.*

Appendix I.

The calculation of design temperatures.

Shellard and Sarson[1] produced charts which enable the designer to estimate for what proportion of a month the ambient air temperature will exceed a given value. The data required are monthly averages of daily maximum and minimum temperatures for the nearest representative met. station[2].

The chart for March is shown as an illustration (other months are given in the reference [1] or [3].)

To determine the design temperature:

1. Note the value of the function $(t-\dot{t})/(t_x - t_n) = f$ for the required probability.
2. Using the temperature data for the location, calculate $\dot{t}$ ($\dot{t} = (t_x + t_n)/2$) and $t_x - t_n$.
3. The desired design temperature can then be obtained by substitution into the equation.
   $t = f\ (t_x - t_n) + \dot{t}$
   t_x = monthly mean of daily maximum temperatures
   t_n = monthly mean of daily minimum temperatures
   $\dot{t}$ = monthly mean of average daily temperature
   t = design temperature

[1] *Shellard, H. C. and Sarson, P. B. Estimation of frequency distributions of hourly temperatures at UK stations for monthly averages of daily maxima and minima. Met. Mag., Vol. 91, (p.19) HMSO*

[2] *Monthly weather report. Met. office HMSO.*

[3] *Heating and cooling load calculations by Down, P. G. Pergamon Press.*

Appendix 2

°F 80 per cent RH	34°F	36	38	40	42	44	46	48	50	60	°C 80 per cent RH
	Store Temperature at 92 per cent RH										
60°F	0·88 32·82	0·82 30·59	0·76 28·35	0·69 25·74	0·62 23·13	0·55 20·52	0·48 17·90	0·41 15·29	0·33 11·31	0·11 –4·10	15·6°C
65	1·10 41·03	1·04 38·79	0·98 36·55	0·91 33·94	0·82 30·59	0·78 29·09	0·70 26·11	0·63 23·50	0·55 20·52	0·12 4·48	18·3
70	1·34 49·98	1·28 47·74	1·21 45·13	1·15 42·90	1·08 40·28	1·02 38·05	0·95 35·44	0·87 32·45	0·80 29·84	0·37 13·80	21·1
75	1·59 59·31	1·53 57·07	1·47 54·83	1·41 52·59	1·34 49·98	1·28 47·74	1·21 45·13	1·14 42·52	1·06 39·54	0·64 23·87	23·9
80	1·87 69·75	1·82 67·89	1·76 65·65	1·69 63·04	1·63 60·80	1·56 58·19	1·49 55·58	1·42 52·97	1·35 50·36	0·93 34·69	26·7
85	2·18 81·31	2·12 79·08	2·07 77·21	2·00 74·60	1·94 72·36	1·88 70·12	1·81 67·51	1·74 64·90	1·66 61·92	1·25 46·63	29·4
	1·1	2·2	3·3	4·4	5·6	6·7	7·8	8·9	10·0	15·6	

Btu/ft³

KJ/m³

THE INSTITUTION OF AG

AUTUMN NATION

Combined with a *C/GR*

SUGAR BEET AND POTATO

to be held at the NATIONAL COLLEGE OF AG
on 2, 3 and 4 O

Convenor: Professor P.

2 October

ASPECTS OF THE MECHANISATION OF THE SUGAR BEET CROP

Chairman: C. Culpin (Past President *IAgrE*) and
British National Representative on *CIGR.*

A Survey of European Production of Sugar Beet

by J. Jorritsma, Instituut voor Rationale Suiker Productie,
Bergen op Zoom, Netherlands.

Developments in the Mechanisation of Soil Preparation and Establishment of the Sugar Beet Crop

by M. Martens, l'Institute Belge pour l'amelioration de la
Betterave, Tienen, Belgium, and
D. R. Brisbourne, Agricultural Development, British Sugar Corporation, *UK.*

Discussion

Trends in Sugar Beet Harvester Design and Systems of Handling

by W. Brinkman, Institut fur Landtechnik der Universitat Bonn, W. Germany.

Performance Assessment of Beet Harvesting Machinery

by G. Maughan, British Sugar Corporation, *UK.*

Discussion

RICULTURAL ENGINEERS

AL MEETING 1972

Section III Meeting

PRODUCTION IN EUROPE

RICULTURAL ENGINEERING, Silsoe, Bedford,
ctober 1972.

C. J. Payne *(NCAE)*

3 October	**VISITS ARRANGED BY THE BRITISH SUGAR CORPORATION** **or** **ASPECTS OF THE MECHANISATION ON THE POTATO CROP** Chairman: P. C. J. Payne
	A Survey of European Production of Potatoes by J. M. Glotzbach, Commodity Board for Potatoes, The Netherlands.
	Aspects of Soil Preparation and Planting for the Potato Crop by D. E. van der Zaag, European Association for Potato Research, and F .E. Shotton, Terrington Experimental Husbandry Farm, Norfolk, *UK*. **Discussion**
	Recent Developments in Potato Harvesting Machinery by D. McRae, National Institute of Agricultural Engineering, Scottish Station, Penicuik, *UK*.
	Performance Assessment of Machinery for the Potato Crop by I. Rutherford, *ADAS* Liaison Unit, *NIAE*, Silsoe, *UK*. **Discussion**
4 October	**Visit to the Potato Marketing Board Harvester Demonstration, Driffield, Yorkshire.**
Note	Simultaneous translation facilities in French, German and English will be available for all the paper presentations.
Conference Dinner Speakers:	J. A. C. Gibb, President Institution of Agricultural Engineers and F. Coolman, President Section III *CIGR*.

Annual Meeting and Dinner

THE 27th Annual General Meeting of the Institution of Agricultural Engineers was held at the Institution of Civil Engineers, London SW1, on 9 May. This was preceded by the Presidential Address given by Mr C. Culpin (fully printed from page 38 of this issue).

Officers elected were President: Mr J. A. C. Gibb *MA MSc FRAgrS FIAgrE MemASAE;* President Elect: Mr J. V. Fox *NDAgrE NDA FIAgrE;* Hon. Treasurer: Mr J. C. Turner *FIAgrE;* Ordinary Members of Council: Messrs K. M. Base *NDA NDPH FIAgrE;* F. M. Inns *MA MSC FIAgrE MIMechE;* R. F. Norman *BSc (Agric.) MSc (Agric. Eng.) FIAgrE;* W. T. A. Rundle *FIAgrE;* D. H. Rowe *MIAgrE;* G. Spoor *BSc (Agric.) MSc (Agric. Eng.) MIAgrE;* F. D. Swift *CIAgrE;* R. J. Fryett *AIAgrE* and P. R. Phillips *GIAgrE*.

The Annual Meeting was followed in the afternoon by further papers on Engineering—for Pig Production, two already having been given in the morning prior to the meeting.

The Annual Dinner of the Institution was held at Quaglino's, Bury Street, St James's, London SW1 in the evening, presided over by Mr J. A. C. Gibb who proposed the Loyal Toast. The address of welcome was given by President Elect Mr J. V. Fox and the Guest of Honour, who also proposed the toast to the Institution of Agricultural Engineers, was Sir Alan Wilson, Chairman of Glaxo Group Ltd. The response was given by the President.

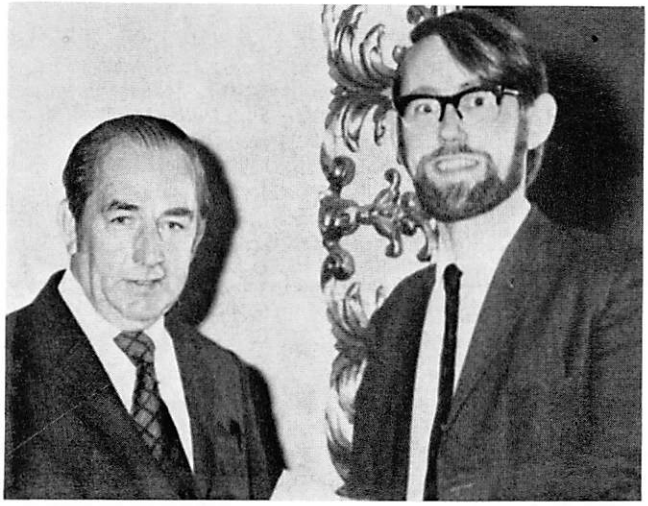
The attendance of just under 100 included members from branches throughout the country, caught by the camera (see below) in a jovial mood.

From left to right: Mr G. Spoor, Prof. P. C. J. Payne, Mr G. Carpenter, Mr J. C. Hawkins (South East Midlands Branch).

From left to right: Mr C. R. Clarke (South Western Branch), Mr B. J. Bell, Mr J. B. Mott (East Anglian Branch).

From left to right: Mr K. A. McLean, Capt. E. N. Griffith, Mr G. C. Mouat (South Eastern Branch), Mr J. Sarsfield (Wrekin Sub-Branch).

From left to right: Mr J. V. Fox (President-Elect), Mr F. D. Jeppeson, Mr J. A. C. Gibb (President), Sir Alan Wilson.



Left to right: Mr D. P. Evans and Mr J. R. Ashley-Smith (Yorkshire Branch).

Left to right: Mr R. D. S. Barber and Mr H. E. Codd (East Midlands Branch).

ERB—The Register is Open

ABOUT 800 members of the Institution are now eligible for registration by the Engineers' Registration Board (*ERB*), if they so wish, and those concerned will receive letters about it in a few weeks time. These notes are intended to follow on from the article in the Newsdesk section of the *Journal*, Vol. 26, No. 1 p. 6, and to remind all members of what is involved.

ERB has been set up by the 15 institutions comprising the Council of Engineering Institutions (*CEI*) and a large number of other engineering institutions, including the Institution of Agricultural Engineers. Its function is to register the names of properly-qualified engineers in three Registers. These are:

1. Chartered Engineers, entitled to the designation *C Eng.*
2. Technician Engineers, entitled to the designation *T Eng (CEI).*
3. Engineering Technicians, entitled to the designation *Tech (CEI).*

Eligibility

At the present time only suitably-qualified members of the 15 *CEI* institutions are entitled to be registered as Chartered Engineers (*C Eng*). Membership of *I Agr E* does NOT constitute an eligible qualification although every effort is being made to find a route by which those Members and Fellows qualified at the level of a degree in agricultural engineering may be so registered.

The registers now open to the 800 members mentioned are the *T Eng (CEI)* section and the *Tech (CEI)* section. The requirements for *T Eng (CEI)* will normally be satisfied by members of *I Agr E* in the Member grade, although certain experienced Graduates and highly-qualified Technician Associates will also be eligible. All Technician Associates will normally meet the requirements for *Tech (CEI).* Institution members in the Fellow grade will also normally be eligible for *T Eng (CEI)* registration—but see "Who should register?" below. Because the requirements for registration depend in part on training and experience there will be a number of members who are offered registration initially in a lower register than the one to which they will aspire eventually.

Cost and Benefit

The arrangements made by *ERB* provide for an annual fee to be paid by individual institutions for participation in each register, plus an annual fee for each registered member. The Institution of Agricultural Engineers will meet these costs through an annual registration fee of £1 payable by each eligible member who wishes to be registered. Eligible members who nevertheless do NOT wish to be registered as *T Eng (CEI)* or *Tech (CEI)* are under no obligation to pay this annual fee which is, of course, additional to their subscription as members of *I Agr E.*

The benefit to be derived from registration is the security and satisfaction to be obtained from national recognition as an accredited Technician Engineer or Engineering Technician, with the right to use the abbreviated designation after one's name.

Who Should Register?

It is hoped that a substantial proportion of eligible members will consider that the benefits of registration are worth the relatively small annual charge. As their careers develop, some of those in Register 3 will become eligible for transfer to Register 2. In due course, when a means is available for opening Register 1 to members of non-*CEI* institutions who are qualified at degree level, transfer from Register 2 should be possible. In regretting that the *C Eng* register is not immediately available to us, we have to remember that we are in the same position as a substantial number of other engineering institutions outside the *CEI* ring fence and that the pressure to find a means of admitting suitably-qualified members of these institutions is very considerable. The building of such a bridge into this jealously-guarded compound is bound to be a difficult and protracted process, but remains the ultimate logical step in the integration of the engineering profession as a whole.

Consequently, Institution members who already meet the criteria for designation as Chartered Engineers, but cannot yet be registered because they are not members of a *CEI* institution, may feel that they would not wish to accept registration in the *T Eng* register, even though fully entitled to it.

Members who do not yet meet the *C Eng* criteria, or who do not expect to have the opportunity to do so, but are eligible for other registers have everything to gain by claiming their right of admission to the *T Eng* or *Tech (CEI)* sections. Admission can be requested at any time, but will be dealt with most expeditiously for those now eligible, and with the minimum amount of form-filling, if advantage is taken of the opportunity to register with the large initial batch of registrations under *I Agr E* sponsorship.

AROUND THE BRANCHES

East Anglian

AT the annual general meeting of the East Anglian Branch, held at Diss on 24 March, Mr Brian Bell succeeded Mr Urban Curson as chairman. Mr Bell is Senior Lecturer in Farm Machinery at the East Suffolk Institute of Agriculture, Otley.

The two vice-chairman are Mr Martin Clough, Senior Lecturer in Agricultural Engineering at the College of Arts and Technology, King's Lynn, and Mr Geoffrey Wakeham, engineer in charge of the development and testing department, farm machinery division of Ransomes Sims & Jefferies Ltd.

Other members forming the committee are Messrs T. B. Dingle, R. A. den Engelsè, R. E. Goldsmith, P. J. Higgs, G. L. Hunt, K. H. Miller, R. B. Ransome, J. C. H. Richman, J. Shewring, B. C. Spofforth, C. E. Westripp, R. N. Cutting, J. B. Mott.

South Western

THE South Western Branch enjoyed a full programme of winter meetings, held at various venues in the Branch area, in places as far apart as Liskeard, Cornwall; Exeter, Taunton and Okehampton.

The subjects included *Soil Cultivation,* by Mr Rowland Thomas *(ADAS); The Field Experimental Unit and Work in the South West,* by Dr Rycroft *(MAFF); Manure Handling Systems,* by Mr D. Williams *(ADAS); Grain Handling, Storage and Conditioning,* by Mr H. Peterson (Electricity Council), Mr John Derrick (grain merchant) and Mr Steve Martin (Henry Norrington & Son Ltd, Exeter).

West Midlands

THE annual general meeting followed by the annual dinner, of the West Midlands Branch, took place at the Manor Hotel, Meriden, Warwickshire, on 14 April.

Branch officers elected for the ensuing year were: chairman—Mr Cecil Cowley (retired), vice-chairman—Mr John Alcock (Bomford & Evershed Ltd), hon. treasurer—Mr H. F. Howells (*M-F* Ltd), honorary secretary—Mr M. J. Bowyer (*M-F* Ltd), press officer—Mr H. V. Billington (Mid-Warwickshire College of Further Education), hon. auditor—Mr D. Ferris (*M-F* Ltd).

The newly elected chairman presided at the dinner which attracted 110 people, and the toast to the West Midlands Branch was proposed by Mr S. L. Potter *CIAgrE,* (Dunlop Rubber Company Ltd), who thought we may well have been guilty of sitting back on our laurels for the past few years in the agricultural industry, and in industry generally. After the golden years from 1950 to 1965, when British-made products were unchallenged in world markets, we may have become complacent.

We, in Britain, had the most highly mechanised agriculture in the world. Other countries had, to a large extent, caught up with us in mechanisation, and cost was the criterion—our problem now was to contain costs and to remain competitive.

Profit margins, he said, were eroded by discount selling, and there were many strong competitors from the Common Market countries.

Up to now, the traditional tractor layout with pneumatic tyres and hydraulic linkage had reigned supreme, with most implements designed around the tractor, but perhaps we should be thinking of a completely new approach.

In his reply, as President of the Institution, Mr Claude Culpin agreed that we were nowhere near the end of the road in farm mechanisation, and prophesied that there would be a great development in the next 25 years in mechanised feeding of livestock.

Mr Dudley Rowe, retiring chairman, proposing the toast to the guests spoke of the increase in Branch membership, and Mr G. H. Jackson (Principal the Mid-Warwickshire College of Agriculture) replying for the guests, stressed the importance of the Institution in its role as a watchdog of governments and an advisor on the far-reaching changes in agriculture.

Members of the West Midlands Branch with National officers at the Branch annual dinner.

A MIXED party of some 16 strong from the West Midlands Branch visited Mitchells and Butlers Cape Hill Brewery on 6 May, last.

The site, which covers some 100 acres, claimed to be an exceptionally high figure for an industrial establishment in the heart of Birmingham, was founded in the 1860's, when the enterprises of Mr Mitchell and Mr Butler were brought together.

The party saw the whole process, from the in-take of barley for malting, the hops on the hop blending floor, and the multi-level flow process resulting in, first, the malt extract arriving at the copper distillation vessels, then the formation of hop extract, which gives beer its bitter flavour and, finally, the tanks in which the *mash* becomes truly beer with the addition of yeast and sugar, and upon which excise duty is paid.

It would appear that the biggest bill to be paid by the brewery is the excise payment of *one million pounds a* month.

The party was shown the modern German multiple control system for the brewing process, and the guide described the free allowance system by which workers receive the 'daily pintas'.

Western

IN anticipation of their talk on four-wheel drive tractors at their March meeting, a group of some 30 members of the Western Branch visited the Bristol Road, Gloucester, works of Muir-Hill Ltd.

In three groups, the Branch members toured the raw materials store, sheet metal work and machining shops, and sub-assembly areas, finishing at the main assembly line.

The company make their industrial four-wheel drive loading shovels in the same works, and their agricultural tractors were derived from these.

The first tractor produced was the 101, incorporating a Ford 5000 transmission, to which is added their own reduction gear box, own axles with inboard disc brakes, and in the first machine a 6-cylinder Ford 2715*E* engine.

The visit was rounded off by a visit to the company's test bay, to see a stationery '101' put through its paces.

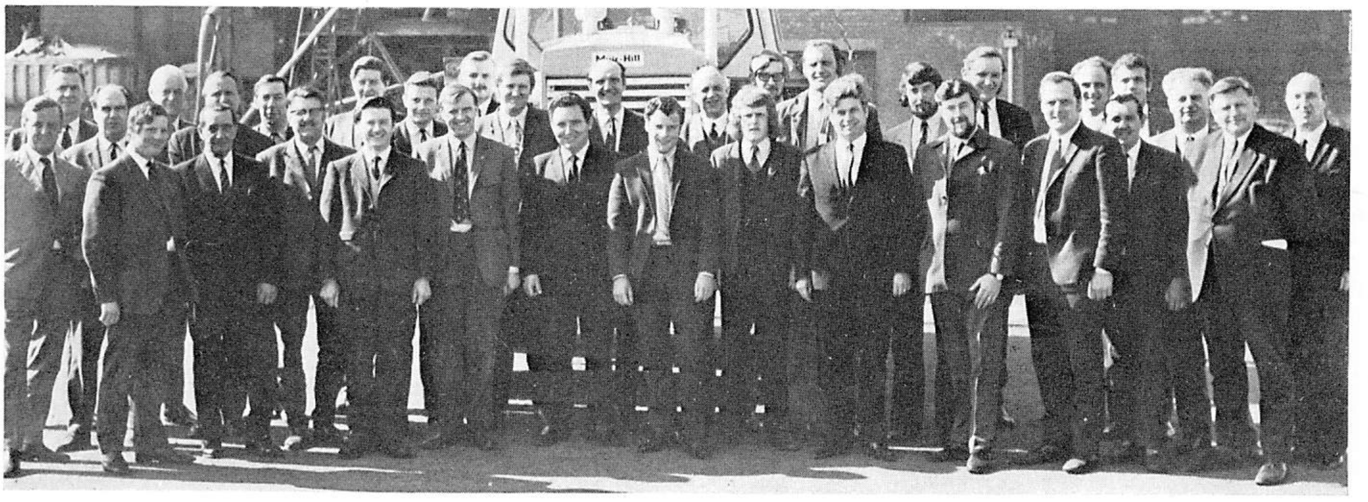
The talk in the evening, at the Royal Agricultural College, Cirencester, was by Mr E. D. King, Muir-Hill's engineering director.

Yorkshire

MEMBERS of the Yorkshire Branch had seven open meetings during the winter starting with *New Methods of Grain Conservation*, by Mr D. J. Greig (University of Newcastle), at Askham Bryan College of Agriculture and Horticulture. Mr Greig said that all grain storage techniques were aimed at the control of moulds, bacteria, insects and respiration by the control of moisture, temperature and oxygen, and went on to describe in considerable detail of operation of low volume ventilation; bulk storage drying; acid storage and sealed storage.

In November, Mr C. L. Cawood, an expert on ancient and modern tractors and their specifications, entertained an audience of 28 at the Lupsett Hotel, Wakefield, with *A Survey of Imported European Tractors*. He listed to the meeting the European tractors available in the *UK* and with the help of illustrations described their individual features and the reasons for their importation. He concluded his talk with a few words about the availability of spares and of service facilities for imported tractors.

Members of the Western Branch recently visited the Muir-Hill Works in Gloucester.



Sound Deadened Steel was the subject of Mr J. A. Profit's talk at the December meeting, held at the Griffin Hotel, Leeds. Mr Profit gave his audience an insight into the reasons why the British Steel Corporation had decided that a sound deadened steel should be developed. He then explained the special techniques and considerations needed to manipulate and fabricate in this new material.

Mr C. J. Chisholm *(NIAE)* lectured an audience of 36 at Askham Bryan College of Agriculture, in January, on *The Present and Future of the Safety Cab.* He dealt at length with the current knowledge on the safety cab, and said that virtually all knowledge and testing procedure derived from the original Scandinavian work.

Safety, he said, was not a saleable commodity and legislation had proved to be the only method of assuring use and preventing fatalities.

Mr C. R. Garner (Ransomes Sims & Jefferies Ltd) posed the question in February, at the Lupsett Hotel, Wakefield, *Is Cultivating Equipment Designed or Does it Just Happen?* He stated the requirement to be borne in mind when developing a new implement; tractor compatibility, cost, layout, and effect on tractor stability.

Mounted were the simplest and cheapest whereas semi-mounted removed many problems of lift capacity and tractor stability.

An audience of 41 heard Mr H. E. Ashfield (David Brown Tractors), at the March meeting, present *Why the Present Tractor Configuration.* This dealt with the necessity of keeping tractors in their present form.

●

THE annual general meeting of the Yorkshire Branch was held at the Griffin Hotel, Leeds, on 23 March, with *IAgrE* President Mr C. Culpin in attendance.

Officers and Committee for the ensuing year are: chairman—Mr G. A. S. Frank, vice-chairman—Dr M. J. Hawker, secretary/treasurer—Mr J. R. Ashley-Smith, committee—Messrs C. H. Hull, R. Chambers, J. Maughan, P. J. Hulbert, E. Brogden, R. Hirons.

Mr J. H. Nicholls, a founder committee member of the Yorkshire Branch, a former Branch chairman, and at one time on the Council of *IAgrE* retired after 15 years service.

NEWSDESK

Electricity in Agriculture

THE 5th International Working Meeting of the *Commission Internationale de Génie Rural,* which will deal with electricity in agriculture, takes place in Berlin (West) from 31 January to 3 February 1973. Suitable visits are being organised to places of interest.

Dri-Crops 73

ABOUT 300 delegates are expected to attend the First International Green Crop Drying Congress—DRI-CROPS 73—which is to be held at Oxford University from 8-13 April 1973. A full programme of papers and discussions will be supplemented by visits to two British research centres and a flying visit to Denmark to see the Shell grass drying farm in Jutland.

Further details from DRI-CROPS 73, Agroup House, 16 Lonsdale Gardens, Tunbridge Wells, Kent.

IAgrE Autumn National Meeting

THE Institution's Autumn National Meeting will be on *Sugar Beet and Potato Production in Europe,* from 2-4 October 1972, at the National College, Silsoe, Beds.

As the objective of this conference is to compare and contrast developments in the *UK* and on the continent, it is said to provide an ideal opportunity to stage the first full conference of Section III (Power and Machinery) of *CIGR** in this country.

In addition to the programme of lectures, visits have been arranged to a sugar factory at Wissington, and the Potato Marketing Board Harvester Demonstration, Driffield, Yorks.

**Commission Internationale du Génie Rural is an international association of professional agricultural engineers, which originated in 1930 and now draws its membership from 18 nations.*

The Professional Institutions Conservation Group

THE inaugural meeting of the Professional Institutions Conservation Group was held in London on 27 June 1972. The Group has developed from the activities of earlier groups working in connection with the various conferences on 'The Countryside in 1970'.

Fifteen Professional Institutions were represented at the meeting, the *IAgrE* being represented by B. A. May. Some 35 other organisations including *CEI, MAFF,* and *NFU* agreed to send observers to the first and subsequent meetings.

Included in the terms of reference for the Group is the aim 'to encourage greater liaison and co-operation between the professions concerned with the planning, management and development of natural resources including land, air and water'. During his opening address, The Rev. The Lord Sanford, Under Secretary of State, The Department of the Environment, welcomed the formation of the Group and stressed the need for multi-disciplinary action in Conservation.

It is envisaged that the Group will be arranging about four meetings each year. Details of meetings will be published in THE AGRICULTURAL ENGINEER as they become known. Should any members require further information please contact either Mr H. Weavers or Mr B. May.

PERSONAL

THE new chairman of The British Institute of Agricultural Consultants is **Mr P. Finn-Kelcey DFH CEng MIEE FIAgrE.** He succeeds **Dr R. C. Woodward MA BSc PhD(Cantab) FIBiol**, now a vice-president.

●

TWO members of the Institution have this year been elected to the higher echelons of the Agricultural Engineers Association, they are **Mr J. H. W. Wilder OBE BA(Cantab) FIAgrE FRAgS**, who is first vice-president, and **Mr W. T. Alan Rundle FIAgrE**, who is second vice-president.

Mr Wilder, a past President of the Institution, is chairman of the *BSI* Agricultural Machinery Industry Standards Committee. He is managing director of John Wilder (Engineering) Ltd, Wallingford, Berks.

Mr Rundle, who is on the Council of the Institution, is chairman and managing director of Wright Rain Ltd, Ringwood, Hants.

INSTITUTION members were prominent at the Annual Conference of Lecturers in Agricultural Engineering recently held at Wye College. The group includes Messrs **D. J. Greig** (Newcastle), **D. W. I. Brooke** (Reading), **H. M. Shepherd** (Aberdeen), **W. Martin** (N. Ireland), **R. P. Heath** (Seale-Hayne), **J. Kilgour** (*NCAE*, Silsoe), **C. Rothery** (Writtle), **B. Wilton** (Nottingham), **I. D. Gedye, P. Thirtle** and **R. Bradley** (Harper Adams), **A. Metianu** and **R. Leggatt** (West of Scotland), **A. Hardie** and **D. A. Jack** (Edinburgh), **A. Costley** and **P. Kennedy** (Shuttleworth) and **R. D. Bell** and **J. M. Wilkes** (Wye).

Terotechnology

"Terotechnology is the technology of installation, commissioning, maintenance, replacement and removal of plant, machinery and equipment, of feedback to operation and design thereof, and to related subjects and practices."

THE Secretary and I represented the Institution at a one day symposium on Terotechnology on 24 May, sponsored by the Institution of Plant Engineers and attended by some 300 people from roughly 50 engineering institutions. The day's proceedings were set in perspective by an introductory address by Prince Philip in his capacity as President of the Council of Engineering Institutions, and it was agreed before the symposium closed both that *CEI* should be asked to establish a professional co-ordinating body and that consideration should be given to establishing a Council on Terotechnology, possibly based on the National Council for Quality and Reliability and kindred bodies.

During the course of the day the definition of terotechnology given above was questioned as was the name itself —derived from the Greek words meaning " care engineering". It became clear that it covered very much more than maintenance engineering, that it was a "horizontal" technology embracing all engineering disciplines, and that it was already practised to a substantial extent in the aerospace industry and in the armed services. The feedback of information to designers was stressed, and it was agreed that terotechnology must start and finish at the design office. Equipment should be designed in the first instance for efficient production, long life and ease of maintenance, while maintenance itself (if still required) could be made more efficient, both as a preventive and corrective function.

The added costs of a terotechnological approach to design were considered to some extent, but specific examples of very substantial cost savings over the life-time of equipment designed in this way were also given. The need for a quantitative approach to the possibilities of applying terotechnology was stressed, and in particular to the collection of data by which the success of terotechnological design could be measured. Savings of £400 million to £500 million a year were thought to be possible, taking manufacturing industry in Britain as a whole.

The question of the relevance of terotechnology to agricultural engineers is, of course, the one we must examine. The only reference during the day to agricultural engineering was, regrettably, an unflattering one. There are two conflicting aspects. One is the often rather short term approach of the purchaser of farm equipment, in which minimum initial cost has traditionally figured very largely. The longer term benefits of reliability in service and reduced maintenance cost have only just begun to be appreciated by more than a few farmers. The second point is that those very qualities, especially reliability, are at least as vital to farmers as to any other kind of industrial user. The consequences of failure may be less dramatic and physically disastrous in farming production than in the aircraft industry, but may be catastrophic in a financial sense none the less.

To some extent, terotechnology can be said to be an attitude of mind on the part of the designer, to be encouraged in every way provided that the cost bears a clear and favourable relationship to the benefits derived. As a "horizontal" technology the principles and advantages of terotechnology must apply to agricultural engineering as much as to any other branch of engineering. The feedback which is essential to improved terotechnology is something the Institution is very well equipped to provide, while many members are already involved in the design of agricultural machines and equipment, at the point at which a terotechnological approach must make its first impact.

For the present, the Institution is not called upon to do more than take note of the very real interest in the possibilities of terotechnology evidenced by a large and influential attendance at the symposium referred to, and perhaps for individual members to consider what possibilities may lie in their own spheres of interest. As the pattern of development unfolds, of a professional engineering approach to terotechnology, and possibly of a National Council of Terotechnology, it will be a matter for Council to consider in what ways the Institution might wish to be associated with it.

J. A. C. Gibb

Note: The Secretary holds a compendium of recent articles on Terotechnology, issued at the symposium. Photocopies of these are available to members on request under the terms of the Institution's normal scheme.

OBITUARY

Mr V. H. F. HOPKINS *CEng FIMechE FIAgrE MSAE*, a past Vice-President of the Institution, died suddenly at his home, Broom Cottage, West Wittering, on 8 April, aged 66 years. He had a lifelong interest in diesel engines and spent much of his career in the field of research; he turned to consultancy upon his retirement from industry.

FORTHCOMING EVENTS

September 14 — *IAgrE* Yorkshire Branch meeting. *Environmental Control in Glass Houses* (including a tour of glass houses at Askham Bryan College.

September 28 — *Work Efficiency and Safety in Agriculture*, joint meeting of the Ergonomics Research Society and the British Society for Agricultural Labour Science, National College of Agricultural Engineering, Silsoe, Bedford.

October 2-4 — *IAgrE* Autumn National Meeting. *Sugar Beet and Potato Production in Europe*, at the National College of Agricultural Engineering, Silsoe, Bedford.

19 — *IAgrE* Yorkshire Branch meeting. *Developments in Agricultural Tyre Design*, Lupsett Hotel, Wakefield.

LETTER TO THE EDITOR

Fowler's Steam-Plough

AS you may know Darlington appears to possess the only monument to John Fowler and his steam plough. This monument, a bronze model of 3-furrow balance plough in the South Park, is now in need of considerable repair, and I am hoping to trace original plans, models or even a detailed photograph of the monument which would assist in reconstructing the plough to its original state. The *Journal of the Royal Agricultural Society*, Vol 19 (1858) contains on page 325 a drawing of this plough, but of insufficient detail to use as a working diagram.

I would be most grateful for any information you could provide, or any sources you could suggest which might help me locate the necessary illustrations. I have also written to the Royal Agricultural Society, who are unable to help, and to the Science Museum for guidance.

S. C. DEAN *FLA AMBIM*,
Borough Librarian and Curator,
County Borough of Darlington,
Crown Street,
Darlington DL1 1ND.

Members are invited to write direct to Mr Dean if they are able to provide any information which would assist the progress of this most worthwhile project.—Editor.

ADMISSIONS AND TRANSFERS

AT a meeting of the Council of the Institution on 26 January 1972 the following candidates were admitted to the Institution or transferred from one grade to another.

ADMISSIONS

Fellow

Do The Gia ... ... *France*

Member

Abarikwu, O. I. ... ... *Nigeria*
Brogden, M. E. ... ... *Yorkshire*
Kaketo, H. D. ... ... *Uganda*
Konschel, C. A. ... ... *Rhodesia*
Okudo, U. P. ... ... *Nigeria*
Ovens, G. ... ... *Malawi*
Ramand, E. ... ... *London*
Robinson, E. P. ... ... *Australia*
Stansfield, J. R. ... ... *Bedfordshire*

General Associate

Adlard, C. J. E. ... ... *Lincolnshire*
Albaya de Gago, J. M. ... ... *Yorkshire*
Bates, B. G. ... ... *Essex*
Causer, D. A. ... ... *Staffordshire*
Costley, A. G. ... ... *Bedfordshire*
Freestone, G. M. ... ... *Huntingdonshire*
Jepson, J. ... ... *Cheshire*
Kirk, D. R. ... ... *Essex*
Lloyd, M. ... ... *Hampshire*
Mander-Jones, D. E. W. ... ... *Warwickshire*
Marshall, E. ... ... *Lancashire*
Mitchell, R. A. F. ... ... *Cambridgeshire*
Ness, J. R. ... ... *South Africa*
Noble, D. ... ... *Nottinghamshire*
Pearson, J. A. ... ... *Buckinghamshire*
Pinkerton, I. M. ... ... *Essex*
Scantlebury, B. ... ... *Essex*
Semple, A. J. ... ... *Shropshire*
Smart, R. C. M. ... ... *West Lothian*
Spencer, P. G. ... ... *Yorkshire*
Thorpe, A. ... ... *Yorkshire*
Tottie, D. R. ... ... *Yorkshire*
Wakeman, P. R. ... ... *Bedfordshire*
Waterfield, G. G. ... ... *Nottinghamshire*
Wynn, B. R. ... ... *Shropshire*

Technician Associate

Camplin, J. ... ... *Oxfordshire*
Green, B. F. ... ... *Yorkshire*
Higgin, J. C. ... ... *Rhodesia*
Lock, K. ... ... *Warwickshire*
Nuttall, B. ... ... *Warwickshire*
Rawlings, A. C. ... ... *Staffordshire*
Rich, D. P. T. ... ... *Hertfordshire*
Richardson, J. L. ... ... *Worcestershire*
Shirley, I. R. ... ... *Warwickshire*
Storey, S. ... ... *Yorkshire*

Graduate

Baker, M. W. ... ... *Lincolnshire*
Cermak-z-Uhrinova, J. P. ... ... *Hampshire*
Fayoriju, M. F. ... ... *Nigeria*
Garrod, I. W. S. ... ... *Lancashire*
Hunt, P. J. ... ... *Kent*
Ong, A. W. ... ... *Malaysia*
Sims, B. G. ... ... *Middlesex*
Woodward, R. E. ... ... *Shropshire*

Student

Archer, P. G. ... ... *Lancashire*
Arter, D. O. ... ... *Kent*
Back, H. L. ... ... *Essex*
Barber, R. W. ... ... *Norfolk*
Bibby, F. R. ... ... *Essex*
Bunting, G. W. ... ... *Derbyshire*
Cooke, J. S. ... ... *Essex*
Ebrahim, B. H. ... ... *Bedfordshire*
Evans, H. O. ... ... *Caernarvonshire*
Grainger, M. F. ... ... *Essex*
Kidson, D. I. ... ... *Yorkshire*
Landers, A. J. ... ... *Essex*
McNicoll, A. A. ... ... *Perthshire*
Mahdi, I. K. ... ... *Essex*
Nwankwo, J. O. ... ... *Ayrshire*
Owen, D. G. ... ... *Hampshire*
Padwick, W. R. M. ... ... *Hampshire*
Rees, M. S. ... ... *Essex*
Richardson, T. J. N. ... ... *Ireland*
Richardson, W. ... ... *Yorkshire*
Sahota, J. S. ... ... *Middlesex*
Squire, M. D. ... ... *Dorset*
Sweetman, J. A. ... ... *Devon*
Tullett, K. N. ... ... *Essex*
Vinden, M. H. ... ... *Bedfordshire*
Voss, R. M. ... ... *Warwickshire*

TRANSFERS

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Ballard, R. A. ... ... *Middlesex*
Betts, R. J. S. ... ... *Sussex*
Cox, A. A. ... ... *Ireland*
Jamieson, M. ... ... *Bedfordshire*
Mackie, W. W. ... ... *Gloucestershire*
Miller, A. F. S. ... ... *Rhodesia*
Morris, A. ... ... *Warwickshire*
Neale, M. A. ... ... *Huntingdonshire*
Sanders, G. B. ... ... *Northamptonshire*
Statham, R. N. ... ... *South Africa*
Tong, P. S. ... ... *Aberdeen*

Technician Associate

Agyei-Amoama, C. K. ... ... *Ghana*
Allen, J. W. ... ... *Suffolk*
Anderson, P. ... ... *Berkshire*
Anstee, P. ... ... *Kenya*
Appleton, G. W. ... ... *Yorkshire*
Arnold, O. T. ... ... *Northamptonshire*
Axford, S. J. ... ... *Cornwall*
Baldwin, G. W. ... ... *Surrey*
Banwell, M. G. ... ... *Kent*
Bashford, A. V. ... ... *Warwickshire*
Bayley, J. J. ... ... *Rhodesia*
Belding, E. T. ... ... *Surrey*
Bennett, P. C. ... ... *Hampshire*
Bishop, J. ... ... *Essex*
Bishop, R. W. C. ... ... *Somerset*
Blackford, R. ... ... *Worcestershire*
Blackwell, P. R. D. ... ... *Kent*
Boden, C. E. ... ... *Lincolnshire*
Bonner, R. H. ... ... *Kent*
Boult, G. J. ... ... *Lancashire*
Bracey, J. F. A. ... ... *Hertfordshire*
Brimblecombe, P. C. ... ... *Nigeria*
Brutey, C. V. ... ... *Hertfordshire*
Burcombe, R. J. ... ... *Gloucestershire*
Burns, R. ... ... *Derbyshire*
Burton, R. J. G. ... ... *Co. Durham*
Calderwood, R. T. ... ... *Ayrshire*
Calvert, P. N. ... ... *Bedfordshire*
Casley, H. R. ... ... *Suffolk*
Caton, A. ... ... *Cambridgeshire*
Chambers, R. ... ... *Yorkshire*
Chapman, R. M. D. ... ... *Hertfordshire*
Chave, B. J. ... ... *Wiltshire*
Clayphon, J. E. ... ... *Berkshire*
Cluett, M. G. ... ... *Dorset*
Cole, P. L. ... ... *Warwickshire*
Crosthwaite, R. P. ... ... *Buckinghamshire*
Dalton, J. R. ... ... *Shropshire*
Dalton, J. W. ... ... *Suffolk*
Davis, D. A. E. ... ... *Bedfordshire*
Davis, M. F. ... ... *Shropshire*
Dee, J. C. ... ... *Gloucestershire*
Dingle, T. B. ... ... *Norfolk*
Dix, M. C. ... ... *Shropshire*
Donovan, J. W. ... ... *Pembrokeshire*
Edghill, G. ... ... *Zambia*
Edmunds, M. J. ... ... *Devon*

Elston, B. A.	*Essex*
Felstead, C. W.	*Hampshire*
Ford, W. R.	*Yorkshire*
Foulger, S. R.	*Shropshire*
Furniss, R. W.	*Yorkshire*
Gladden, R. R.	*Africa*
Godfrey, G. L.	*Somerset*
Gould, J. O.	*Somerset*
Graham, M. W.	*Nigeria*
Griffiths, D. H.	*Worcestershire*
Gundry, R. G.	*Gloucestershire*
Hadfield, H. G.	*Essex*
Hale, O. D.	*Bedfordshire*
Hardwick, L.	*Sussex*
Hartley, P. V.	*Middlesex*
Harvey, E. G.	*Berkshire*
Hayward, A. R.	*Canada*
Heygate, C. N. St. C.	*Devon*
Hiscock, K. C.	*Sussex*
Holden, R. G.	*Uganda*
Holton, N. W.	*Cambridgeshire*
Hoskins, J. O.	*Cardiganshire*
Howard, P. W. J.	*Devon*
Howart, D.	*Stirlingshire*
Hussein, M. H. M.	*Ceylon*
Jefferies, T.	*Cheshire*
Jeffes, R. H. F.	*Gloucestershire*
Johnson, R. A.	*Dorset*
Jones, D. J. H.	*Cardiganshire*
Jones, G. O. S.	*Worcestershire*
Jones, I. C.	*Montgomeryshire*
Jones, J. E.	*Montgomeryshire*
Jones, R. E. W.	*Denbighshire*
Keenlyside, J. F.	*Yorkshire*
Khoo, D. C.	*Malaysia*
Lacey, E. C. F.	*Gloucestershire*
Lacey, R. D. J.	*Gloucestershire*
Lewis, P. G.	*Hampshire*
McCarthy, M.	*Gloucestershire*
McCosh, J.	*Belfast*
McCracken, A.	*Co. Derry*
McKee, F. A.	*Lancashire*
Macpherson, W. O.	*Northumberland*
Mander, C. E.	*Warwickshire*
Millard, W. J.	*Norfolk*
Mohamed, I. B. A.	*West Malaysia*
Molligoda, A. R.	*Ceylon*
Moorhouse, J.	*Yorkshire*
Morgan, V. C. L.	*Yorkshire*
Mugford, F. K.	*Wiltshire*
Munro, R. McL.	*Ross-shire*
Nightingale, J. S.	*Dumfrieshire*
Nutt, G. J.	*Berkshire*
Ofori, R. T.	*Ghana*
Ogundero, S. O. O.	*Nigeria*
Ogunkoya, J. A.	*Nigeria*
Osborne, R. C.	*Suffolk*
Osborne, W. M.	*Monmouthshire*
Page, R. A.	*Rhodesia*
Patel, V. C.	*Uganda*
Paterson, I. G.	*Gloucestershire*
Pemberton, J. D.	*Wiltshire*
Pennycook, K. D.	*Dumfriesshire*
Pomeroy, E. G.	*Wiltshire*
Priestley, P. C.	*Yorkshire*
Purchas, M. D.	*Somerset*

Display advertisements are now being accepted for the Autumn issue, published 15 October. The copy date for these and all Editorial contributions is 1 September. Branch secretaries please note the latter.

Quansah, S. S.	*Ghana*
Robertson, L. N.	*Ecuador*
Robinson, R. E.	*Buckinghamshire*
Rogerson, D. L.	*Canada*
Rosher, C. G. W.	*Yorkshire*
Ruston, I. F.	*Huntingdonshire*
Sears, B. L.	*Derbyshire*
Simpson, C. C.	*Essex*
Sheppard, J. C.	*Lancashire*
Smith, J. C.	*Cambridgeshire*
Spiller, R. G.	*Devon*
Spratt, C. D.	*Lincolnshire*
Spratt, U. G.	*Lincolnshire*
Staines, E. J.	*Warwickshire*
Stamp, J. T.	*Devon*
Storr, K. A.	*Lincolnshire*
Sunderland, R.	*Hampshire*
Suttie, J. S. O.	*West Indies*
Sykes, A.	*Cornwall*
Tatt, I. R.	*Yorkshire*
Taylor, R. N.	*Lancashire*
Thakrar, H. G.	*Uganda*
Theakston, T.	*Yorkshire*
Tolson, D.	*Warwickshire*
Tuck, N. G.	*Suffolk*
Walker, P. H.	*Surrey*
Walker, R. B.	*Staffordshire*
Wallace, J. A. I.	*Cumberland*
Warren, J. D.	*Somerset*
Waterson, R. J.	*Buckinghamshire*
Watts, C. L.	*Yorkshire*
Webb, B. T.	*Wiltshire*
Weeresinghe, P. E.	*Ceylon*
Westgate, G. R.	*Surrey*
Whetnall, C. R.	*Gloucestershire*
White, R. G.	*Hampshire*
Whyte, D. N.	*Nottinghamshire*
Wicks, A. E.	*Kent*
Wilkinson, D. T.	*Lincolnshire*
Wilkes, J. M.	*Kent*
Williams, R.	*Northumberland*
Williamson, A. P.	*Cumberland*
Wolton, A. P.	*Yorkshire*
Woodward, J. L.	*Oxfordshire*

Graduate

Barrett, A. J.	*Essex*
Defeu, D. P.	*Cambridgeshire*
Oldacre, N.	*Essex*
Pepper, A. T.	*Berkshire*
Tan, A. S.	*Malaysia*
Threlkeld, E.	*Derbyshire*
Ward, N.	*Buckinghamshire*
Watts, M. S.	*Hampshire*

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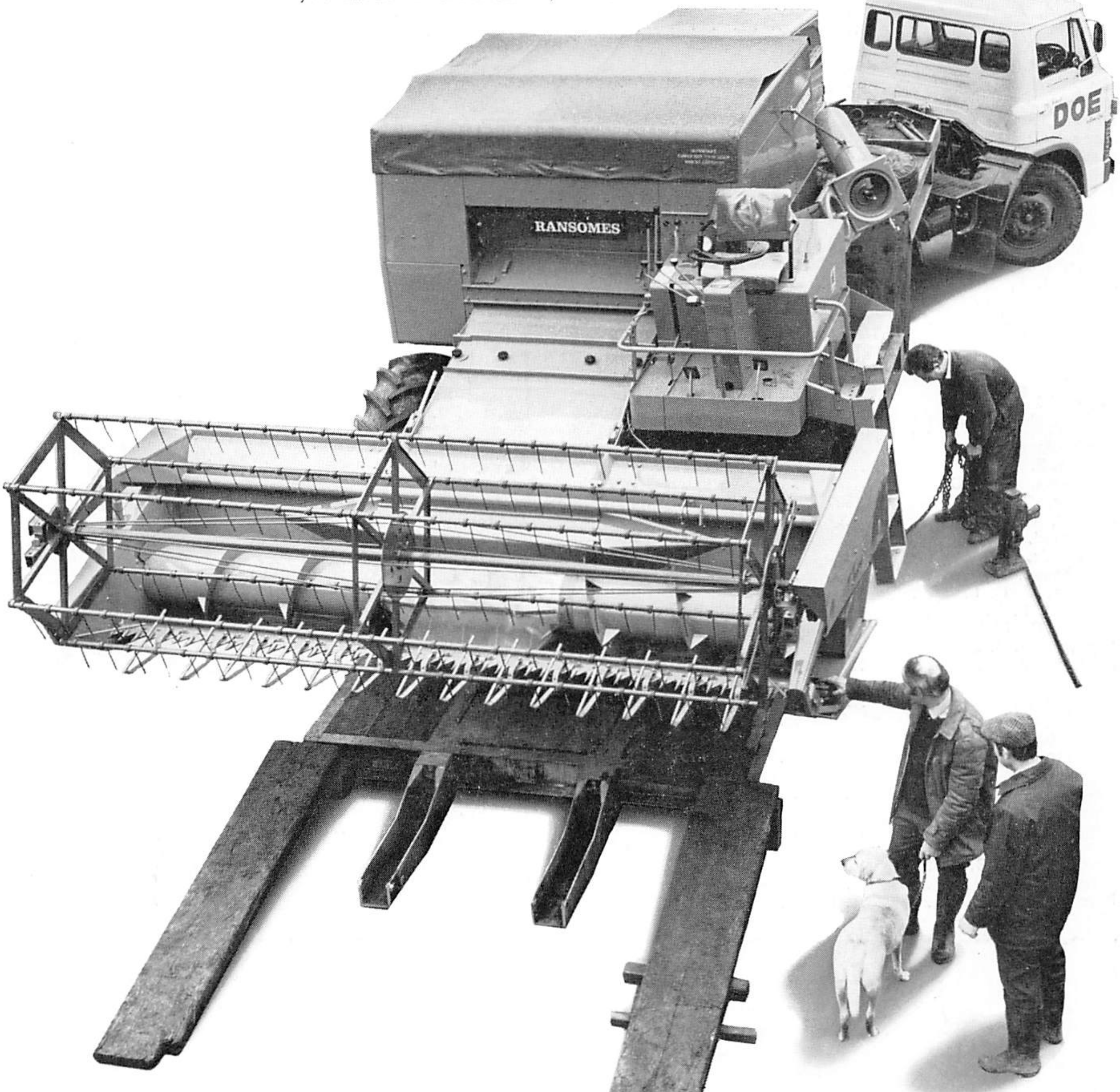

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