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AUTUMN
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THE INSTITUTION OF AGRICULTURAL ENGINEERS

Spring National Open Meeting 1967

THE CONTRIBUTION OF AGRICULTURAL ENGINEERING IN DEVELOPING COUNTRIES

UNIVERSITY OF READING, MAIN SITE, LONDON ROAD, READING, BERKS

on

THURSDAY 16 MARCH 1967

PROGRAMME

09.45 Assemble for Coffee in Great Hall

10.15 PAPER I:
The Application of Agricultural Engineering in Developing Countries
by Professor A. H. Bunting, MSC, D PHIL
Professor of Agricultural Botany and Dean of the Faculty of Agriculture, University of Reading

11.15 PAPER II:
Systems of Mechanization for Agriculture in Developing Tropical Countries
by J. C. Hawkins, BSC(AGR), NDA, MI AGR E
Head of Cultivation Department,
The National Institute of Agricultural Engineering

12.15 **Discussion** of Papers I and II

12.45 Luncheon Interval

14.00 PAPER III:
Conditions Governing Mechanization in the Gezira
by B. P. POTHECARY, MA(ENG), MSC(AGR ENG), MI AGR E
Agricultural Engineer,
The Sudan Gezira Board

15.00 **Open Forum and Discussion** of Papers I, II and III
to include authors and guest contributors

16.00 Tea and Dispersal

TICKETS

Non-Members (other than Students)	...	30/-
Members (other than Students)	...	22/6
Students (non-members)	...	15/-
Students (members)	..	10/-

The above charges cover the following items:
Advance copies (approximately one week ahead) of full texts or synopses of papers (depending upon availability); attendance at morning and afternoon sessions; morning coffee, luncheon and afternoon tea at the University.

EARLY APPLICATION FOR TICKETS IS VERY STRONGLY ADVISED. Applications should be accompanied by remittance payable to 'The Institution of Agricultural Engineers' to reach the Secretary not later than 6 March 1967.

INSTITUTION NOTES

National Open Meetings

It was in the Autumn of 1965 that the Institution began to take its national Open Meetings out of central London. The first of these was at the National College of Agricultural Engineering, Silsoe. The three-figure total of members and guests who came from all over the country made it clear beyond all doubt that this type of whole-day event, geared to a compelling subject-theme, was the key to future planning of the Institution's National Session.

Events have proved this to be the case. In March 1966 the Spring National Open Meeting was held for the first time at the elegant premises of Wye College in Kent. The strongly regional flavour of the subject-theme 'Fruit Husbandry' guaranteed an audience which numbered many prominent fruit growers and horticulturalists. More recently, the 1966 Autumn National Open Meeting was held at the Essex Institute of Agriculture at Writtle, near Chelmsford, a venue traditionally linked to the Institution's educational role, for the Institution's Examinations have been conducted there for many years. It is the first time that an Open Meeting has been held there, however, and despite the comparatively specialized nature of the subject-theme 'Plant Soil and Water', there was again a three-figure attendance.

National Open Meetings of this kind are clearly here to stay and your attention is directed to the page facing these Notes where you will see details of the Spring 1967 Open Meeting to be held at the University of Reading on 16 March. Every member will receive an application form in February and a particular welcome will be extended to students, to whom special ticket prices are available.

Publications

After a break of several years, the Institution has reverted to the practice of publishing in booklet form the Winter Session Programme. This is in response to popular demand and it is hoped that members will find the pocket-sized booklet useful. It may not be generally known that members can attend *any* Institution meeting and not just those run by their own Branch. Members on the move will find that they are welcome at meetings of Branches where they are 'just visiting'. The new booklet should help them.

The 1966-67 Yearbook will be circulated early in the New Year. It will continue in the revised style and format introduced in the previous issue which appears to have found general favour. The latest issue will contain an important 'Message from the President' which will be of interest to every member throughout the world.

Annual Conference and Dinner

Members are asked to make a preliminary note that the Annual Conference of the Institution will be held in the Lecture Theatre of The Institution of Mechanical Engineers, 1 Birdcage Walk, London SW1 on Thursday 11 May 1967. The subject-theme of this whole-day event will be 'Mechanization of Cattle Feeding' and full details will be announced in the near future.

At 12 noon, the Annual General Meeting will be held, immediately following the morning session of the Conference and preceding the luncheon interval.

The Annual Dinner of the Institution will be held in the Ballroom of St Ermin's Hotel, Caxton Street, London SW1 on the evening of 11 May at 6.15 for 7.00 p.m. Full details will be announced very soon.

Examinations

The 1966 examinations for the National Diploma in Agricultural Engineering were held in July at the Essex Institute of Agriculture, Writtle, Chelmsford, Essex and at West of Scotland Agricultural College, Glasgow. Most of those who sat the examinations this year did so under the new arrangements whereby the ND AGR E is awarded by the Examination Board in Agricultural Engineering on the basis of external assessment of examinations arranged by the two above-mentioned training centres. This new system reflects the pattern to be seen in such schemes as the award of the Ordinary and Higher National Certificates and Diplomas in Engineering.

Major structural changes took effect also in the 1966 Institution Part II Examination. From this year onwards, the examination is directed specifically at candidates aged 30 years and over, and remains available to younger candidates up to 1967 only if they can show that they have been engaged on course work or other approved study for the old syllabus.

Detailed results of the 1966 ND AGR E (Old and New Scheme) and Institution Part II Examinations appear on pages 124 and 125 of this issue of the *Journal*. The Institution is once again indebted to the Principals of the Essex Institute of Agriculture, West of Scotland Agricultural College and Rycotewood College, Thame, Oxon, for offering their examination facilities.

NEWS FROM BRANCHES

A Broad Guide

This list is a broad guide as to Institutional activity during the 1966-67 Session and is not intended to be comprehensive. It may be subject to alteration. The list includes nationally organized events and as much information as possible about regional meetings planned by the eight Branches of the Institution at venues in the United Kingdom. Further information will be circulated to members from time to time. The names and addresses of Branch Honorary Secretaries will be found at the end of this Journal.

National Activities

Monday 26 September 1966—9.40 am to 4.30 pm

AUTUMN NATIONAL OPEN MEETING to be held at the Essex Institute of Agriculture, Writtle, **Chelmsford**, Essex.

PLANT SOIL AND WATER

Irrigation Investigations in Relation to Soil and Crop by E. J. Winter, MC, MSC, Head of Irrigation Section National Vegetable Research Station, Wellesbourne.

Water Supply and Storage by K. H. Lambert, BSC, MICE, AMIWE, Senior Engineer, Drainage Division, Ministry of Agriculture, Fisheries and Food.

Factors Affecting the Future of Water Application by J. J. North, BSC, MS, DIP AGR, Crop Husbandry Advisory Officer, National Agricultural Advisory Service.

Jack Wright Memorial Lecture: Irrigation in Arid Lands by E. R. Hoare, BSC(ENG), MIEE, MIE(AUST), MI AGR E Officer-in-Charge, CSIRO Irrigation Research Laboratory, Commonwealth of Australia.

Followed by general discussion of the four papers.

The Jack Wright Memorial Lecture given by Mr Hoare is presented in association with Wright Rain Limited.

Wednesday 16 November 1966—6.00 for 6.30 pm

PHILIP JOHNSON MEMORIAL LECTURE to be held at the Institution of Mechanical Engineers, 1 Birdcage Walk, **London** SW1.

Tribute to a Pioneer and National Gentleman. A paper of both historical and current interest concerning the life and work of the late Lt.-Col. Philip Johnson, CBE, DSO, MI MECH E, HON. MI AGR E, Founder President of the Institution of Agricultural Engineers, presented by J. A. Cuthbertson, OBE, MI AGR E, of James A. Cuthbertson Ltd.

This meeting has been arranged in association with Roadless Traction Co. Ltd.

Thursday 16 March 1967—[Whole day]

SPRING NATIONAL OPEN MEETING to be held at the University of Reading, **Reading**, Berks.

THE CONTRIBUTION OF AGRICULTURAL ENGINEERING IN DEVELOPING COUNTRIES. A series of three Papers and a Panel Discussion featuring Professor A. H. Bunting, BSC, MSC, D PHIL, Dean of the Faculty of Agriculture, University of Reading and other speakers to be announced.

Ticket admission only.

Thursday 11 May 1967—[Whole day]

ANNUAL CONFERENCE to be held at The Institution of Mechanical Engineers, 1 Birdcage Walk, **London** SW1.

THE MECHANIZATION OF CATTLE FEEDING. A series of four Papers and Discussions featuring the following speakers:

R. M. Paterson, CI AGR E, of Rex Peterson Farms Ltd.
J. Moffit, Jnr., of Peepy Farm, Northumberland
V. Beynon, BSC, Senior Lecturer in Agricultural Economics, University of Exeter, and one further speaker (to be announced).

Ticket admission only.

Thursday 11 May 1967—12 noon

ANNUAL GENERAL MEETING of The Institution of Agricultural Engineers, to be held at The Institution of Mechanical Engineers, 1 Birdcage Walk, **London SW1.**

Thursday 11 May 1967—6.15 for 6.45 pm

ANNUAL DINNER to be held at St Ermin's Hotel Caxton Street, **London SW1.**

Guest speakers to be announced.

Ticket admission only.

Further details of all national activities will be released in due course.

East Anglian Branch

Wednesday 30 November 1966—10.30 am to 5.00 pm

ANNUAL CONFERENCE to be held at The Assembly House, **Norwich.**

Chairman: J. H. W. Wilder, BA, MI AGR E (President of the Institution).

CUTTING COSTS OF CULTIVATIONS

The Economic Position by B. M. Camm, MA, MSC, of Farm Planning & Computer Services Ltd.

Development Trends in High Powered Tractors by J. B. Finney, BSC, ND AGR E, NAAS, Machinery Adviser, Berks/Oxon.

Crop Production under Minimal Cultivation Techniques by R. J. Gutsell, of Plant Protection Ltd.

Looking Ahead at Cultivation Trends and their Effect on the Design of Cultivating Implements by a speaker to be announced.

Transmission of Power to Soils by Dr A. R. Reece, BSC(MECH ENG), M SC(AGR ENG), AMI MECH E, AMI AGR E Senior Lecturer in Agricultural Engineering, University of Newcastle-upon-Tyne

User experiences by local farmers and a NAAS survey in Norfolk.

Friday 24 February 1967—

ANNUAL DINNER to be held at the Royal Hotel, **Norwich.**

Thursday 30 March 1967—

ANNUAL GENERAL MEETING to be held at The Assembly House, **Norwich** followed by a discussion on: **Training in the Agricultural Engineering Industry** led by M. S. Searle, AI AGR E, Education Officer AMTDA

SUFFOLK SUB BRANCH

Monday 3 October 1966

VISIT to Testing Department of Ransomes, Sims & Jefferies Ltd., at Nacton, **Ipswich.**

Thursday 24 November 1966

Combine Harvester Development by Manns of Saxham to be held at the Witnesham Agricultural Education Centre, Nr **Ipswich.**

Wednesday 11 January 1967

Selling Farm Machinery Abroad by K. M. Hicks, to be held at Ransomes, Sims & Jefferies Ltd., Nacton **Ipswich.**

Thursday 16 February 1967

Electronics in Agriculture by A.E.I. Ltd., to be held at Witnesham, Nr. **Ipswich** or Hadleigh Road, **Ipswich.**

Further details and times of the above events will be announced.

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at rev/min.	1000/ 2400	1500/ 3000	1500/ 3000	1000/ 2250	1000/ 2500	1000/ 2000	1000/ 2000	1000/ 2250	1000/ 2400	1200/ 2500
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kgm.	15,5	10,1	10,9	20,9	26,7	26,3	31,6	30,2	37,3	52,5
at rev/min.	1200	1900	1900	1350	1400	1000	1150	1250	1000	1500

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NEWS FROM BRANCHES *(continued)*

East Midlands Branch

Thursday 6 October 1966—6.00 for 6.30 pm
Experiences in the Middle East by G. B. H. Spear, ND AGR E, DIP AGR, MEM ASAE, MI AGR E of the National Agricultural Advisory Service. Meeting to be held at the Angel and Royal Hotel, **Grantham.**

Wednesday 19 October 1966—2.30 pm
VISIT to John Deere Ltd., Harby Road, Langar, Nottingham including a paper:
The Power Shift Transmission by N. P. Kingston of John Deere Ltd.

Wednesday 2 November 1966—9.30 am
DAY CONFERENCE to be held at Kesteven Agricultural College, Caythorpe Court, **Grantham.**
Chairman: T. Ensor, of Spring Dairy Farm, Nuneaton.

POTATOES
Cultivations by I. M. Robertson of the National Institute of Agricultural Engineering, Scottish Station.

Storage by C. P. Hampson, of the Potato Marketing Board.

Mechanization by F. E. Shotton, of the Terrington Experimental Husbandry Farm.

Thursday 2 March 1967—7.30 pm
Fuels by a speaker from Shell Mex & B.P. Ltd. Meeting to be held in **Grantham** (venue to be announced).

Tuesday 21 March 1967—7.30 pm
CO2 Welding by C. J. Kemp of the Rowen-Arc Dept, Rubery Owen & Co. Ltd. Meeting to be held in the Main Hall, Rubery Owen & Co. Ltd. Sutton Bonington, **Loughborough.**

Thursday 13 April 1967—7.00 for 7.30 pm
The Pea Crop by A. J. Gane of the Pea Growing Research Organisation. Meeting to be held at the Lindsey Farm Institute, **Riseholme, Lincs.**

Northern Branch

Monday 10 October 1966
Developments in Land Drainage by Dr A. N. Ede, of the Ministry of Agriculture, Fisheries & Food.

Monday 14 November 1966
Artificial Fertilizers and their Application by D. F. Constantine, MA, of Fisons Fertilisers Ltd., (Levington Research Station)

Monday 12 December 1966
Safety in Electrical Installations on the Farm by P. Laughton, MIEE, Senior Inspecting Engineer, National Inspection Council.

Monday 9 January 1967
Future Developments in the Application of Hydraulics in Agriculture by F. A. Cowell.

Monday 13 February 1967
Economics of Machinery Use
Discussion meeting

Monday 13 March 1967
ANNUAL GENERAL MEETING

Further details of venues and times to be announced

Scottish Branch

Tuesday 20 September 1966—2.00 pm
VISIT to Messrs John Dewars & Sons Ltd., Inveralmond, **Perth.**

Tuesday 20 September 1966—3.45 pm
VISIT to Potato Store of David T. Fenton & Sons, Dunkeld Road, **Perth.**

Wednesday 12 October 1966—7.30 pm
JOINT EVENING MEETING with Morayshire Farmers' Club to be held in The Golden Arms Hotel, **Elgin.**
FARMSTEAD ENGINEERING

Tuesday 15 November 1966—7.30 pm
Current Observations on Floor Drying of Grain by J. Robertson, NDA, ND AGR E, AMI AGR E of the National Agricultural Advisory Service, Durham. Meeting to be held at The West of Scotland Agricultural College, **Auchincruive, Ayr.**

Wednesday 16 November 1966—7.30 pm
The above lecture will be repeated at a meeting to be held at The Edinburgh & East of Scotland College of Agriculture, West Mains Road, **Edinburgh 9.**

Tuesday 31 January 1967—
A REVIEW OF DEVELOPMENTS WITH HARVESTING, HANDLING AND STORAGE OF POTATOES
The Speakers will include:
C. P. Hampson, BSC, MI BIOL, Principal Scientific Officer, The Potato Marketing Board, London.
A. R. Wilson, BSC, MS, PHD, MI BIOL, Deputy Director, The Scottish Horticultural Research Station, Mylnefield.
Meeting to be held in The Station Hotel, **Perth**

Wednesday 15 February 1967—7.30 pm
Improvements in Farm Transport by D. P. Blight, BSC, MSC, PHD, AMI MECH E, Senior Scientific Officer, The Scottish Station of The National Institute of Agricultural Engineering, Meeting to be held in The Edinburgh & East of Scotland College of Agriculture, West Mains Road, **Edinburgh 9.**

Thursday 9 March 1967—10.00 am to 4.30 pm
ANNUAL CONFERENCE to be held in the MacRobert Pavilion of The Royal Highland & Agricultural Society at Ingliston, Edinburgh.

MECHANIZATION AND THE FUTURE OF FARMING. Full details to be announced.

ANNUAL GENERAL MEETING AND DINNER will be held on the same day as the Annual Conference.

Further details of venues and times to be announced

South Western Branch

All meetings will commence at 7.30 pm unless otherwise indicated

Thursday 13 October 1966
Grain Handling and Storage by P. H. Bailey, BSC(ENG), MI AGR E of the Tractor and Drier Performance Department, National Institute of Agricultural Engineering and H. Paterson, BSC(AGR), NDA, AMI AGR E, of the Agricultural Advisory Section, The Electricity Council.
Meeting to be held at the Eagle House Hotel, **Launceston.**

Thursday 10 November 1966
Impressions of Agriculture in Russia by W. P. Authers, Past President of the Agricultural Engineers Association.
Meeting to be held at The Cullompton Hotel, **Cullompton.**

Thursday 1 December 1966
Grassland Conservation
Speakers: C. B. Fairbairn, Nutrition Chemist, National Agricultural Advisory Service.
G. E. Tooby, NDA, AMI AGR E, Deputy Regional Mechanization Advisory Officer, National Agricultural Advisory Service.
Meeting will be held at the Three Tuns Hotel, **Honiton.**

Thursday 12 January 1967
Close Row Drilling and Liquid Fertilizing
Speakers: J. G. Barker, MI AGR E, of Western Machinery and Equipment Ltd.
R. J. Davey, AMI AGR E.
Meeting to be held at the South Western Electricity Board, Demonstration Room, **Taunton.**

Thursday 9 February 1967
Cost Accounting in the Retail Agricultural Machinery Trade
Speaker: W. Mitchell, of the Business Management Department, Massey-Ferguson Ltd.
Meeting to be held at The Devon Motel, **Exeter.**

Friday 10 March 1967
JOINT MEETING with the Exeter Panel of the Institution of Mechanical Engineers.
Subject and speaker to be announced.
Meeting to be held at the Royal Clarence Hotel, **Exeter.**

Friday 7 April 1967
ANNUAL GENERAL MEETING AND DINNER (time and venue to be announced)

Western Branch

All meetings to be held at The Bath Arms, **Warminster, Wilts.**

Wednesday 19 October 1966—7.45 pm
Chemicals and Minimal Cultivations by D. Evans, Development Manager, Plant Protection Ltd.

Wednesday 23 November 1966—7.45 pm
Feed and Manure Handling Problems in Large Herds by A. J. Quick, Deputy Regional Dairy Husbandry Adviser, National Agricultural Advisory Service.

Wednesday 15 February 1967—6.30 p.m.
ANNUAL GENERAL MEETING followed by
Haymaking and Feeding by J. M. Monck, Farmer.

Wednesday 22 March 1967—7.45 pm
The Application of Large Tractors to British Farms by R. S. Steven, of John Deere Ltd.

Friday 14 April 1967
ANNUAL DINNER (time to be announced)

West Midlands Branch

All Meetings will be held at Room 118, The College of Advanced Technology, Costa Green, **Birmingham 4** and will commence at 7.30 pm unless otherwise indicated.

Monday 26 September 1966
Plant Breeding for Mechanization by Dr G. D. H. Bell, of the Plant Breeding Institute, Cambridge.

Monday 24 October 1966
Farm Buildings, Mechanization and Control of Environment by Dr D. W. B. Sainsbury, of The University of Cambridge.

Monday 28 November 1966
The Economics of Farm Machinery Investment by G. A. Pain, of Ashorne House Farm, Ashorne, Warwickshire.

Monday 2 January 1967
Value Analysis in Agricultural Engineering by A. G. Horsnail, of The National College of Agricultural Engineering.

Monday 6 February 1967
Growing Crops with Minimum Cultivations by A. Blomfield, of Plant Protection Ltd., Haslemere, Surrey.

Monday 6 March 1967—7.00 pm
SHORT PAPERS EVENING
Agricultural Engineering in the USA by T. H. Padmore of The National College of Agricultural Engineering
The Application of Metal and Wire Belts on the Farm by J. Boydell and G. A. Harvey of Boydell Engineering Ltd.
The Patent Office as an Aid to the Designer by J. L. Howland, of Massey-Ferguson Ltd, Coventry.

Friday 14 April 1967 6.30 pm
ANNUAL GENERAL MEETING venue as for Annual Dinner

Friday 14 April 1967 7.30 pm
ANNUAL DINNER to be held at The Regent Hotel, **Leamington Spa.**

Saturday 6 May 1967
SPRING OUTING
Visit to the Museum of English Rural Life, Shinfield Road, **Reading**, Berks.
Visit to the Department of Agriculture, University of Reading, **Reading**, Berks (details to be announced).

WREKIN SUB-BRANCH

All meetings will commence at 7.30 pm unless otherwise indicated.

Monday 10 October 1966
Grain Drying and Handling Equipment for In-bin and On-the-floor Storage by P. Finn-Kelcey, AMIEE, MI AGR E
Meeting to be held at the Harper Adams Agricultural College, Edgemond, **Newport**, Shropshire.

Monday 14 November 1966
Return to the Tower Silo by Gordan Newman,
Meeting to be held at the Staffordshire Farm Institute, **Rodbaston, Nr Penkridge, Staffs.**

Monday 12 December 1966
Recent Developments in Harvesting and Storage of Potatoes to reduce Damage by C. P. Hampson.
Meeting to be held at the Staffordshire Farm Institute, **Rodbaston, Nr Penkridge, Staffs.**

Monday 9 January 1967
Developments in Plough Design
Meeting to held at the Shrewsbury Technical College, **Shrewsbury.**

Monday 13 February 1967
Buildings and the Control of Environment for Chitting of Seed Potatoes and Storage of Ware Potatoes by H. J. M. Messer.
Meeting to be held at the Harper Adams Agricultural College, Edgemond, **Newport**, Shropshire.

Monday 13 March 1967
The Economic Utilization of Tractor Power
Meeting to be held at the Harper Adams Agricultural College, Edgemond, **Newport**, Shropshire.

THE MECHANIZATION OF VEGETABLE HARVESTING

by J. C. HAWKINS, BSC(AGR), NDA, MI AGR E*

Presented at the Annual Conference of the Institution in London on 12 May 1966

I. INTRODUCTION

The main crops grown on the 412,000 acres or so devoted to vegetables in the United Kingdom in 1962/63 (the last year for which complete detailed statistics have been published) are shown in Table I.[1] For the crops listed in that table, there are generally accepted harvesters only for peas and green beans for processing and for maincrop carrots on some soils: the rest are harvested by hand.

TABLE 1
United Kingdom Acreages of Vegetables for Human Consumption 1962/63

Crop	*Acres* x 1000
Cabbage	74.3
Peas—Canning and freezing	69.9
Fresh market	30.3
Brussels sprouts	50.3
Winter cauliflower	47.7
Carrots	33.2
Lettuce	16.6
Beans—Runner and French	13.5
Broad	12.5
Turnips and swedes	10.2
Beetroot	8.4
Celery	6.2
Rhubarb	5.6
Parsnips	4.8
Onions—Green	3.6
Dry bulb	3.4
Leeks	2.1
Asparagus	1.5
All other vegetables	18.2

The cost of this operation, which naturally varies with the crop, has been estimated to be between half and threequarters of the gross return in North America[2] and the corresponding figure for Britain is probably not very different. An estimate of current harvesting costs for some of the important British vegetables, given in Table II[3], confirms that the engineer usually has a very substantial target at which to aim when he attempts by mechanization to reduce the cost of harvesting. There must, therefore, be good reasons why there are so few vegetable harvesters in production at the present time.

Probably the main reason is that problems of performing mechanically many of the harvesting processes now carried out by hand are so very difficult. For example, many horticultural crops do not mature evenly and growers normally go over them a number of times to select vegetables as they become mature. In mechanizing this operation, it is not easy to devise simple and reliable systems for discriminating between what is ready for harvest and what is not, or methods of removing the mature vegetables without damaging or contaminating those remaining in the field. Further, even if such selective harvesting is not necessary, many vegetables are so easily damaged and thus made unsaleable that harvesting mechanisms reaching the standard of hand work are difficult to find. Secondly, the structure of the horticultural industry, until quite recently, has not encouraged manufacturers to develop vegetable harvesters. Most vegetables in Britain are produced by relatively small growers who could not afford to buy a specialized harvester for every crop or even for one and the number of large growers who could, while increasing, is as yet too small to provide a worthwhile potential market.

TABLE 2
Labour costs in vegetable harvesting

Crop	*Yield per acre*		*Labour for harvesting % of total cost*
Asparagus	$1\frac{1}{2}$ tons		66
Beans, runner	6 tons		28
Beet	14 tons		30
Brussels sprouts	4 tons		28
Cabbage (greens)	8 tons		44
Cabbage, hearted	10 tons		40
Carrots	20 tons		40
Cauliflowers	7 tons	inc. trimming and packing	33
Celery	15 tons		20
Leeks	9 tons	inc. some trimming	33
Lettuce	1200 crates		30
Onions, bulb	12 tons		27
Onions, salad	7 tons	inc. bunching	70
Parsnips	15 tons		48
Peas, market	4 tons		60

II. HARVESTING AIDS

Because of the difficulties outlined above, growers in North America especially, have developed various semi-mechanized systems of harvesting for vegetables and fruit grown on a field scale. All are based on some form of conveyor to eliminate unproductive walking by the pickers and may incorporate some or all of the facilities of a normal packhouse. The simplest consists of a conveyor either towed by a tractor,[4] mounted on a lorry[5] or self-propelled[6] and long enough to span the number of rows to be covered by the picking gang. The pickers place the crop on the conveyor which delivers to containers, into

* Cultivation Department, National Institute of Agricultural Engineering.

a vehicle running alongside or into the body of the lorry. Some versions make provision for carrying the pickers with the conveyor;[7] but these have the disadvantage that the speed of the whole operation is limited to that of the slowest member of the team.[8] The more elaborate types may have provision for operators to trim, grade and pack produce so that it leaves the field in the market pack. Probably the ultimate in this form of semi-mechanized harvesting was reached by celery growers in Florida[9] who developed a machine covering 22 rows and requiring a crew of 58, not including those employed on the maintenance of the equipment. A conveyor fed by the pickers delivered to a packhouse on the machine where the heads were trimmed, washed, graded, packed into crates made on the machine and delivered into a lorry towed behind.

The benefits claimed for harvesting aids based on conveyors are an increase in output of from 30 to 100 %[6] or more[7] with less damage to the crop left in the field. The work of the pickers is much lighter and closer supervision of the packing is possible to ensure a more even product. On the other hand, the mobile conveyor requires more labour than a complete harvester, is often difficult to manoeuvre at the ends of the rows and between fields, and can be seriously handicapped by unfavourable soil conditions. It needs a balanced gang under good leadership, if the slow ones are not to hold back the faster members and there is evidence of increased damage to the produce harvested with some crops[4] although by careful design it should be possible to avoid much of this. The important disadvantages of such harvesting aids for British conditions, however, are that they do not save enough labour: the large gangs which growers are finding it increasingly difficult to muster are still needed to work them and, during the winter, their use would be severely restricted by unfavourable soil and weather conditions and by short days.

III. SELECTIVE HARVESTING

In designing vegetable harvesters, there is a choice between two main lines of approach—selective harvesting and destructive or once-over harvesting. In the first, the machine goes over the crop a number of times, selecting only those vegetables that are ready for harvest, in the second the whole crop is harvested in a single operation. Most of the 'above-ground' vegetables like lettuce and brassica crops do not mature evenly and, as growers have long harvested them selectively by hand, it is natural to think in terms of selective harvesters for such crops.

1. Selection

Successful selective harvesting of any vegetable crop depends on finding physical properties with values which are related to or associated with maturity. Differences between the mature and immature can be used directly to make sure one is harvested and the other left behind or they can be used indirectly as a source of information to control a harvester discriminating between the two. If, as is the case, for example, with cantaloupe melons, mature fruits are more easily detached from the plant than immature ones and have rougher skins, some form of harvester which applies the right amount of force to the fruit by means of friction on the skin should remove the ripe ones and leave the unripe. The physical characteristics of the mature fruit are thus used directly to make the required selection. If, on the other hand, the mature individual is larger and firmer than the immature, as with cabbages and lettuce, the values of these properties can be used indirectly to make the selection. A sensing mechanism capable of determining how large and how firm each head is could decide which ones a harvester removes and which it leaves behind.

(a) *Direct.* When differences in physical properties are used directly to discriminate between the mature and the immature, the harvesters can usually be relatively simple, as in the case of the melon harvester cited above.[10] The plants when young are trained mechanically to grow all one way at right angles to the rows. At harvest they can then be lifted by a sloping conveyor with a suitably rough surface in a harvester moving between the rows. On the way up the conveyor, the melons in contact with the surface are pulled sideways by their stems, because the plants are still firmly rooted in the ground. The force thus applied to them removes some of the ripe fruit; the remainder are removed by gravity when the plants are transferred from the conveyor to a series of narrow belts which allow the fruit to hang down freely. The unripe melons remain attached to the plants which are returned gently to the ground. This process has been repeated on a crop six or seven times without excessive damage to the plants.

Attempts to harvest asparagus selectively have been less successful than with melons.[11] In this crop, the property used to select mature spears has been their length. An experimental harvester to make direct use of differences in length for selection employed a pair of horizontal soft-faced paddle wheels working in conjunction with a fixed level platform with soft edges. The paddles, sweeping across the rows 2 inches above the platform, snapped off against the edges any spears that were tall enough and swept them on to the platform. In field trials some spears were missed by the paddles, broken into small pieces, left on the ground or struck several times by the paddles before they were snapped, with the result that the yield of saleable crop was not high enough to make the operation economic.

(b) *Indirect.* When differences in physical properties are used indirectly to select the mature vegetables, the harvesters are likely to be much more complicated. With this method of selection, three distinct processes are involved. A sensor must first determine the value of the significant property and provide a suitable signal when it encounters a mature vegetable. This signal must then be stored to allow for the horizontal distance between the sensor and the harvesting mechanism, which has to be capable of removing a single plant from a row without damage or contamination and without affecting its neighbours.

Typical of machines of this type are two harvesters for lettuce developed in the U.S.A.[12 13] In one, mature heads are selected by rubber pressure rollers running on each side of the row, in the other by a rubber belt running on top. When heads are both large enough to fill the gap between the rollers and firm enough to force them apart or high enough and firm enough to support the belt at or above a pre-determined distance above the ground, a circuit is completed and a control system causes a knife to cut the selected head from the row. Because the sensor is some distance ahead of the knife, the control system has to measure the forward travel of the harvester and delay the operation of the knife until it reaches the right head. Further, since there will usually be several lettuce heads between the sensor and the knife, the control system must be able to handle several signals from the sensor at the same time. The severed heads are removed from the row either as they are cut, by a basket assembly associated with the knife moving across the row, or after cutting by a rotary elevator with soft fingers, of which the correct ones are released by the control mechanism at the right moment to grip only the severed heads.

Experiments to develop a selective asparagus harvester, using a measure of spear height indirectly to control selection, have again been much less successful. None of the attempts, using feelers, air jets, or photo-electric devices to sense spears tall enough to be harvested have as yet proved suitable for commercial use.[11] Mechanical feelers deflected the spears and introduced errors, the magnitude of which depended on the stiffness and diameter of the spears: a jet of air, used to hold a switch open until it was interrupted by a spear of the required length, failed because of vibration and wind effects: and photo-electric devices have proved to be unreliable near the soil where there is likelihood of much dust under dry conditions.

2. The Value of Selective Harvesting

With crops that do not mature evenly, selective harvesting would be expected to produce the maximum yield of first quality produce from each acre. Further, since such crops are now harvested this way by hand, mechanization could be adopted by growers with the minimum amount of change. Selective harvesting does, however, have a number of disadvantages. It is necessary to use planting patterns which provide paths through the mature crop wide enough to accommodate the wheels of tractors, harvesters and transport in order to reduce the risk of damage to vegetables remaining in the field. Such patterns are often far from those established as ideal by modern research which has shown that the yield in a desirable size grade and the evenness of the samples in many vegetables can be influenced a good deal by plant spacing.[14] In general, higher populations give higher yields and fewer excessively large vegetables when the individual plants are spaced evenly over the whole field. If, however, paths through the crop for wheels are required to make repeated selective harvesting possible, such an even plant distribution is not attainable. Plants in the rows bordering on the paths will be subjected to much less inter-plant competition than the rest and many are likely to grow too large for the top grade so reducing the total value of the crop. It is likely then, that the potential increase in yield to be expected from selective as opposed to once-over harvesting might be reduced substantially by losses from this source.

If, however, paths wide enough to avoid mechanical damage to the adjacent rows by wheels are acceptable, there is still a risk that under some soil conditions, particularly in the winter, the crop will lose value by being contaminated by mud falling from wheels or by soil removed from the crop by the harvester. It is possible, too, that fuel or lubricants from equipment running over the standing crop might introduce a new form of contamination not readily removed by normal washing processes. Finally, where neither paths nor contamination are likely to be direct sources of loss in yield, there is still a strong possibility that repeated passes of the harvester mechanism through some crops or repeated handling of the plants to detect the mature vegetables will cause unacceptable damage and loss. In work on cucumber[5] in the U.S.A., for example, these operations and those necessary to train the plant to grow in a way that simplified selective harvesting resulted in a total loss in the gross value of the crop of some 75%.[15]

IV. ONCE-OVER HARVESTING

With root vegetables like carrots, red beet, turnips, parsnips and onions, once-over harvesting is usual, as it is with crops like leeks and celery where most of the valuable part is in the soil. It is only with cabbage, cauliflower, sprouts, lettuce, beans and similar crops, where the valuable part is above ground, that selective harvesting is considered to be necessary. Fresh peas and French beans were at one time in this category, as they still are when grown on a garden scale, but the need to harvest large quantities quickly and cheaply for processing has made mechanization necessary and these crops are now grown in such a way that mechanical harvesting can be a once-over operation. This development, considered in conjunction with the difficulties of producing satisfactory selective harvesters and their inherent disadvantages, suggests that the same approach might be adopted for the other above-ground vegetables. This is, in fact, what has happened with cucumbers in the U.S.A. The unsuccessful attempts to develop a selective harvester, already quoted, prompted experiments on once-over harvesting.[16] In the course of these, a successful harvester was developed with crop loss figures of 14% or less.

Once-over harvesting has a number of advantages, the chief of which is that it is usually a very much simpler operation calling for a simpler machine than selective harvesting. There is no need for highly specialised and sophisticated sensing, discriminating and control devices for each vegetable. In fact, without these, there is the possibility that one machine can be made to handle a number of crops of similar habit. Further, when the land is cleared in one operation, the plants are handled once only and there is no need for any wheel to run in the standing crop. Risks of damage and contamination are thus much reduced and the planting pattern does not have to include paths for wheels of the tractor, harvester and transport. The layout adopted for once-over harvesting can, therefore, more nearly approach the ideal of an even plant distribution over the whole field, with the population adjusted to give the highest possible proportion of produce in any desired size grade.

1. Crops

The main disadvantage of once-over harvesting comes from the fact that so many of the varieties of the above-ground vegetables currently grown mature unevenly. A proportion of the crop is, therefore, either immature or past its best on a single harvesting date and has to be discarded or sold at a lower price as second grade produce. The net loss in yield may not, however, be quite as high as might be expected because the absence of the wider pathways required for selective harvesting may give some yield increase. In theory, there is for every crop a break-even ratio of hand harvested yield of saleable produce to machine harvested yield when the saving in harvesting costs compensates for the loss in yield. The indications are that this would not often be reached with the current varieties of above-ground vegetables as they are now grown on most holdings. For once-over harvesting to be adopted on any scale, ways must be found of increasing the proportion of above-ground crops which is mature at any given time. Such a development involves work in a number of fields including plant breeding, plant physiology and agronomy.

(a) *Plant Breeding*. Because it usually makes the design of harvesters very much easier and leads to a simpler machine, the breeding of a special variety of a crop tailored to mechanical harvesting is an approach which should always be considered. The trouble is that it is often such a lengthy process that mechanization has to be introduced before the breeding programme can be completed and at a time when the break-even ratio has not been reached. Nevertheless, there will usually be a number of growers who are prepared to accept for a while a slightly lower return from their crops mechanically harvested, because labour is just not available for hand work. This is the situation with most crops in Britain at the present time, in spite of work by plant breeders well ahead of demands by growers. As their work continues, the break-even ratio will undoubtedly be reached with many crops and mechanized once-over harvesting accepted without question.

The most important characteristic for once-over harvesting is, of course, even maturity and breeders have made striking progress in this direction with Fl hybrids in a number of vegetables, including cabbages and Brussels sprouts.[17] There are now commercially available varieties in which all the sprouts from the bottom to the top of the stem can be ready for picking at the same time and cabbages with which practically every plant in a field is ready for cutting at once. The same stage of development has not yet been reached with lettuce; but it does not appear to be unattainable. Cauliflowers, however, present a more difficult problem, because at cutting time the plants are at the bud stage of flowering and so their development has probably been affected as much by their environment up to that time as by their genetical make-up.

Evenness in maturity brings problems for the average grower, who usually plans to supply a market over a long period or has to meet a contract to deliver a fixed quantity at a specified time. In spite of the most careful spacing of sowing dates, the subsequent weather may be such that several sowings or plantings mature at the same time, the crop can be early or late for the contract date or the market may be glutted and the prices low when the crop is ready. To deal with such situations, the grower will want his crops which mature evenly to have the ability to stay mature and in good condition for as long as possible. If this is not practicable, then the produce should store well under conditions which are not too difficult or expensive to provide on normal commercial holdings. In fact, the adoption of successful once-over harvesting for some crops may depend on the provision of storage by the grower.

While the characteristics of evenness of maturity and holding ability are the most important for once-over harvesting, there will be others which will materially help any form of mechanized harvesting, just as the breeding of short stiff strawed varieties of cereals has helped in combine harvesting. A good example of such a character is that introduced into varieties of outdoor tomatoes bred specially for mechanical harvesting in the U.S.A.[18] There plant breeders have managed to combine with even maturity, dwarf habit, disease resistance and earliness, the character of a tough skin. This reduces greatly the proportion of fruit split by the harvesters and yet does not detract from the value of the crop because all mechanically harvested fruit is used for processing.

Mechanized Brussels sprout harvesting in Britain would be easier with varieties which shed all their leaves when the sprouts were mature or had very brittle petioles to make mechanical leaf removal a simple operation. With root vegetables, and carrots in particular, good strong upright and frost-resistant tops would help harvesting by providing 'handles' by which the roots could be lifted from the ground throughout the winter. These and similar characters, however, are not of such general importance as a feature like resistance to damage because the need for them depends on the particular design that the engineer chooses for a harvester. They cannot, therefore, be given first priority by plant breeders, who usually have a formidable task in adding evenness of maturity and holding ability to the list of characters like high yield, good quality, pest and disease resistance, earliness or winter hardiness for which they are always breeding.

(b) *Plant Physiology*. The work of the plant breeder can be supplemented by that of the plant physiologist. By greater understanding of the factors affecting the growth and development of plants, practical techniques can be evolved for producing even maturity while retaining high yields of good quality produce. For example, work on the effects of such factors in cauliflower production as date of sowing, planting techniques, varieties, spacing, day length and temperatures is suggesting that it will be possible to grow a succession of evenly maturing crops suitable for once-over harvesting. Similar work with many other vegetable crops has established the relationships, already mentioned, between spatial arrangement, populations, total yield and yield in particular size grades.[14]

Although with once-over harvesting it is not usually necessary to depart so far from an ideal plant arrangement as with selective harvesting, it may still be essential to modify the plant physiologist's ideal pattern in order to accommodate the machine. In carrots, for example, it has been established that rows of individual plants as close as $2\frac{1}{2}$ in. apart over the whole field or even broadcasting can give higher yields, better quality and a more uniform crop than the conventional rows 12 or more inches apart. Such an arrangement, however, is not very suitable for mechanization because mechanical harvesting is essentially a process of dealing with a single discreet strip of crop at a time. If the field has not been planted as a series of such strips, with spaces clear of plants between each one, a proportion of the crop will be damaged or lost in harvesting. In separating the strip to be harvested from the rest of the field, the edge of the share would damage many root vegetables like carrots and with aboveground vegetables like lettuce, the dividers required would cause similar damage.

When a departure from an ideal plant arrangement is necessary, work by plant physiologists can establish a pattern which, while approaching the ideal for crop quality and yield as closely as possible, makes mechanized harvesting practicable. In other crops, too, spatial arrangement can have a marked effect on how easily harvesting can be mechanized. Closer spacing of suitable varieties of Brussels sprouts, for example, can contribute to even maturity and may also encourage the growth of straight stems which stand well and so are more easily harvested. An understanding of crop development may even suggest such approaches as a change from transplanting to seeding, or the use of carefully controlled irrigation or fertilizer applications to modify the habit of a crop so that it can be harvested more easily.

2. Agronomy

The introduction of mechanized once-over vegetable harvesting will certainly be made simpler and may, in some cases, be made possible by changes in the way that crops are grown. Much can be done by plant breeders to produce a variety which has the potential for the evenness of maturity necessary for once-over harvesting; but, if it is not grown correctly, it will not produce an even crop in the field at harvest time. When the aim is even maturity, the grower must do all he can to see that every plant is growing in the same environment and receives the same treatment up to harvest. The seedbed must be as even as possible and free from wheelmarks, so that a form of bed cultivation will usually be preferable for all crops grown in rows closer than about 18 in. Drilling or transplanting should be carried out so that each seed or seedling is planted in the same way and at the same depth and spacing. Fertilizer, irrigation water, herbicides or protective sprays, too, should be applied as evenly as possible.

With once-over mechanical harvesting, a sound even sample of vegetables and effective pest and disease control are much more important than with hand methods. Workers harvesting by hand can very easily select only those vegetables that are of marketable quality: a harvester will gather them all. If the mechanically harvested sample then contains a high proportion of damaged, mis-shapen, diseased, under-sized, overgrown or otherwise unsaleable vegetables, the problem of removing these may make the whole operation uneconomic. Attempts to make a separation on the harvester may require so much additional mechanism that the machine becomes too complicated, heavy and expensive or its output and labour saving may be brought below the break-even point by the number of pickers needed on the machine. Even if no separation or grading is attempted in the field, these operations will still have to be done in the packhouse where the problems will be the same with the additional one of having to transport so much unwanted material from the field. The effects on harvesting efficiency of a high proportion of unsaleable produce has been demonstrated in carrots. In a crop with 75% of the roots unsaleable because of splitting in the soil, hand picking behind an elevator digger was practicable and gave a good sample which could be washed and graded in a normal packhouse. Mechanical harvesting was unsatisfactory because it was quite impracticable either to pick off all the split carrots on the harvester or to remove them by hand at the washing and grading plant.

The need for changes in row width or for the arrangement of rows in groups to accommodate harvesters has already been mentioned; but, superimposed on this, may be the need for new planting programmes. When the demands of a market are to be met by the repeated selective harvesting of a crop by hand, a relatively large area can be planted at one time. With once-over harvesting, however, the grower would usually have to make a carefully planned succession of plantings, in order to supply a market with good quality produce over a similar period: although any inherent ability of the crop to remain mature and in good condition for a long period would simplify this. In the same way, some form of controlled storage for harvested produce would help to ensure a regular supply, especially in the winter, when there are likely to be days when harvesting by hand would have been possible and harvesting by machine is not.

V. COMPLETE HARVESTERS

With both selective and once-over harvesting there can be two broad objectives in harvester design—to produce a finished sample on the machine in the field or to transfer some of the final preparation of the crop from the field to stationary equipment elsewhere. For a finished sample, a complete harvester must carry out a number of operations after a first stage of digging plus soil separation, or cutting or picking of the crop. Before a final inspection and grading stage, crops like cabbages, cauliflowers, lettuce, leeks and celery would need to be trimmed, sprouts stripped from the stems and cleaned and root vegetables topped and perhaps tailed. Such operations are usually specific to a particular crop and so complete harvesters, like all selective harvesters, will usually be designed for one crop only or for a small group of crops which are very similar in habit.

Complete harvesters have the advantages that, given an adequate acreage, they will usually provide the cheapest method of harvesting, labour requirement can be reduced to the minimum and the least amount of material has to be transported from the field. The rate of work can be high, because the output is not restricted by the speed at which any operation is carried out by hand or by the number of workers that can be accommodated on the machine. For these reasons, complete harvesters are very suitable for harvesting crops to supply the demands of packing and processing plants and modern mechanized green bean or pea harvesting for freezing are good examples of large machines being used efficiently in this way.

Complete harvesters are, however, usually large and relatively heavy machines because of the number of different processes that they have to carry out. They may, therefore, be difficult to handle under British conditions especially in the winter, although in North America, where many such machines have been developed for irrigated crops in dry areas, such troubles do not occur. Because of their size and complexity, they are also likely to be expensive and so economic only for contractors or large growers. Taking American tomato harvesters as an example, prices quoted in 1963 ranged from \$3,500 to \$15,000[18] and such complete harvesters were said to be economic only for growers of 100 acres or more.[19] The potential market for them will, therefore, remain small with little chance of the price being reduced by the adoption of modern quantity production methods.

The yield of first quality produce from any given crop is unlikely to be as high with complete harvesters as it would have been with good hand work. For example, the successful selective melon harvester, described in Section III, removed 96% of the ripe fruit at the first pick without damage; but nearly 20% of those remaining on the plants showed some damage when they were subsequently harvested. Further, the total recovery of saleable fruit was 10 to 25% less than from hand work. In contrast the less successful experimental asparagus harvester, in gathering between 66.7 and 84.5% of the total marketable weight, caused so much damage that only 47.0 to 58.6% of this was of marketable quality. The once-over cucumber harvester, quoted in Section IV, damaged between 5 and 9% of the crop depending on the variety and the conditions.

Such damage figures may not, however, be so serious if the vegetables are destined for processing rather than for the fresh market. Standards for acceptable levels of contamination and damage, established when a plant was supplied with produce harvested by hand, may not be easily attained with mechanical harvesting. In order to take advantage of the economies possible with mechanization, therefore, it may be necessary to make changes in organization or in processing equipment so that some of these standards can be relaxed. The introduction of tomato harvesters in the United States for example, has been made possible in this way. Damage in the form of splits and bruises was so severe that a mechanically harvested crop would have been quite unacceptable on the fresh market. However, by arranging for rapid processing as soon as possible after harvesting, such damage could be tolerated and a satisfactory end product produced.[20] Greater contamination, too, could probably be accepted with some crops by the addition of relatively simple equipment to the head of a processing line. In another field, sugar mills which had been designed to crush clean cane harvested and loaded by hand, have been able, by the addition of a cleaning and washing plant or 'cane laundry' as the first stage, to accept mechanically harvested or loaded cane containing substantial amounts of soil and trash.[21] A similar approach in vegetable processing could simplify some of the problems of complete mechanized harvesting.

VI. SIMPLE HARVESTERS

The alternative to complete vegetable harvesters is a much simpler machine designed to harvest crops with the minimum amount of trimming, cleaning, inspection, grading and packing on the machine. A certain amount of such processing with some crops always has to be done in the field, because it is so very much easier to do it there. Roots, like carrots and beetroot, for example, are more easily topped as they are lifted than later and as much soil as possible has to be removed from them so that a washer can accept the sample produced. Onions, on the other hand, should not be topped and cleaned as they are being harvested because these operations are more effective after the crop has been conditioned artificially.[22]

The main purpose of the simple harvester, therefore, is to load clean and undamaged produce into containers or vehicles for final treatment elsewhere. Usually this will be in a packhouse with a specially planned trimming, washing, grading and packing line designed to receive produce in bulk and to handle a larger volume of waste than usual. Here vegetables can be prepared for market under good working conditions and with the necessary supervision to ensure a uniform product.

A complete harvesting system will, therefore, consist of the harvester and a specialized packhouse with an efficient transport and handling system linking the two. This system must be designed to deal with relatively large quantities of easily damaged produce at a speed that will allow full use to be made of the harvester especially when days are short in the winter. The potential output of such harvesters is likely to be so high that crops cannot be handled economically in small units, like bags, crates or bushel boxes, unless these are necessary to avoid damage or contamination. Lettuce in good condition, for example, is so tender that damage to the lower layers from the pressure of those above would be inevitable with handling in bulk or in large containers. Leeks, too, have to be handled in relatively small units because it is important to pack them all one way before washing in order to avoid contamination of the leaf axils with soil from the roots.

In addition many crops are far too bulky as harvested to be handled in anything smaller than trailers or very large box pallets. A well-base $36 \times 36 \times 28$ in. box pallet, which holds about 5 cwt of potatoes, will hold only 120 cabbages as harvested—representing about 50 yards of row—or 115 stems of sprouts—the produce of about 60 yards of row. To hold the produce of an acre of cabbages, therefore, requires about 200 of these boxes and an acre of sprouts 120 boxes. Expressed in another way, a harvester travelling at about 2 mile/h in these crops would fill one such box every minute. Clearly, few growers would be justified in investing so much capital in small box pallets or would be able to organize a complete system of mechanical handling that could keep the number of boxes required within bounds, without risk of holding up the harvester.

With a relatively few simple operations to be carried out in the field it is possible to design a universal vegetable harvester in the form of a basic machine, with one or two attachments to adapt it for a wide range of crops. Because it is relatively simple, it can be light and manoeuvrable and so often more suitable than complete harvesters for British field conditions in the autumn and winter. It should also be much cheaper than complete or selective harvesters and so, with the cost spread over a number of crops, within the reach of the majority of growers who have relatively small acreages and grow several different vegetables. Thus a universal harvester would be required in much larger numbers than specialized selective or complete machines and might well be suitable for large scale production methods. From the contractor's point of view, too, a machine which can be employed for most of the year is often of some interest.

Although the introduction of simple harvesters of this type would be likely to present new agronomic, management and handling problems it is probable that these would be less complex than those thrown up by specialized single crop machines. Further, the ability to harvest a number of crops with the one harvester may permit a flexibility of cropping hardly possible with other types. For example, a large grower of Brussels sprouts, who has recently mechanized his harvesting with an expensive highly specialized complete machine, might be reluctant to change to some other crop which had become more profitable: a change he would not hesitate to make with a universal harvester.

The chief disadvantage of a vegetable harvesting system based on a simple universal machine, is that the labour requirement will usually be higher than with specialized complete harvesters. The difference will not be proportionately as great as between grain harvesting based on a binder and based on a combine, for example, because an increasing proportion of vegetable crops are being washed, close-graded and pre-packed by processes which it is not practicable to carry out on a harvester. Transport between field and packhouse will, however, often be more expensive because larger quantities are involved and because more unwanted material, removed in trimming and grading, has to be carted away. On the other hand, because crops are transported untrimmed and some handwork is involved in the final preparation for sale, damage can be very much less. There is, in fact, no reason why crops harvested by a simple harvester and prepared for sale in a special packhouse should be of a lower standard than would be expected from hand harvesting.

VII. SUMMARY AND CONCLUSIONS

1. Although harvesting by hand accounts for between 20% and 70% of the total costs of production few vegetable harvesters have been developed because it is not easy to mechanize the usual selective harvesting of easily damaged produce and because most growers plant a relatively small acreage of several crops.

2. Harvesting aids, based on conveyors to receive vegetables from a number of pickers harvesting by hand, while effecting some saving in labour, are unlikely to be suitable for the future.

3. As the long term objective, once-over or destructive vegetable harvesting is always to be preferred to selective harvesting.
   - (*a*) When selective harvesting is required a direct system of selection is to be preferred to an indirect one.
   - (*b*) With selective harvesting, it is necessary to use planting patterns differing from the ideal to a greater extent than with once-over harvesting.
   - (*c*) There is greater risk of damage and contamination to the growing crop with selective harvesting.

4. Once-over harvesting is already accepted for below-ground vegetables; but demands special crops and growing techniques before it can be adopted for all above-ground ones.
   - (*a*) Crops for once-over harvesting should both mature evenly and remain in good condition when mature for as long as possible.
   - (*b*) Efficient and economic storage of harvested produce is likely to be more important with once-over harvesting.

5. Complete harvesters, producing a finished sample of vegetables in the field are usually more suitable for supplying processing plants than the fresh market.
   - (*a*) Complete harvesters can be used for one crop only or for a small number of similar crops.
   - (*b*) The labour demand is usually lowest and output highest with complete harvesters.
   - (*c*) The cost of complete harvesters makes them suitable only for contractors or large growers.
   - (*d*) Complete harvesters cause more damage than good hand work and in many cases the sample produced has been suitable only for processing.
   - (*e*) The adoption of complete harvesting may be facilitated by changes in organization or equipment at processing plants.

6. Simple harvesters, used in conjunction with a mechanized pack-house to produce the finished sample, are more suitable for supplying the fresh market and for smaller growers.
   - (*a*) Simple harvesters can be designed to harvest a wide range of vegetable crops.

(*b*) For some crops the labour required with a simple harvester is higher than with a complete harvester.

(*c*) Simple harvesters are lighter and more manoeuvrable and so are more suitable for work in the autumn and winter.

(*d*) A harvesting system based on a simple harvester, with efficient transport and handling to a well-planned pack-house, is capable of producing vegetables of as high a quality as the best hand work.

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NEWS FROM BRANCHES (*continued from page* 82)

Yorkshire Branch

All meetings will commence at 7.30 pm unless otherwise indicated.

Friday 30 September 1966
Bearings for Agricultural Tractors by A. Wright, of British Timken Ltd.
Meeting to be held at The Strafford Arms Hotel, Wakefield, Yorks.

Friday 28 October 1966
The Development of Minimum Cultivation Techniques by E. Staniforth, AMI AGR E of Sisis Equipment (Macclesfield) Ltd.
Meeting to be held at The Elm Bank Hotel, Tadcaster Road, York.

Monday 14 November 1966
The above lecture will be repeated at a meeting to be held at The Greyhound Motel, East Lancashire Road, Leigh, Lancs.

Monday 25 November 1966
The Implement Manufacturer's View of the Future of the Agricultural Tractor by G. Wakeham, GI MECH E, GR I AGR E, ND AGR E of Ransomes, Sims & Jefferies Ltd.
Meeting to be held at The Griffin Hotel, Boar Lane, Leeds 1, Yorks.

Friday 3 February 1967
Welding Techniques for Production and Maintenance of Agricultural Tractors and Machinery by R. Shelton, AIW of David Brown Tractors Ltd.
Meeting to be held at The Strafford Arms Hotel, Wakefield, Yorks (venue subject to alteration).

Monday 13 February 1967
The above lecture will be repeated at a meeting to be held at The Greyhound Motel, East Lancashire Road, Leigh, Lancs.

Friday 3 March 1967
ANNUAL GENERAL MEETING to be followed by an *Open Meeting* (subject of paper to be announced), To be held at The Griffin Hotel, Boar Lane, Leeds 1, Yorks

Friday 7 April 1967
The Economics of Grain Conservation and Mechanized Feeding Systems by J. I. Payne, AMI AGR E, ND AGR E of the National Agricultural Advisory Service.
Meeting to be held at The Elm Bank Hotel, Tadcaster Road, York

Tuesday 11 April 1967
JOINT MEETING with the North Eastern Centre of the Automobile Division of the Institution of Mechanical Engineers.

Engine Wear and Air Filtration for Engines Working in Dusty Conditions by T. C. D. Manby, MSC, BSC, MI AGR E of The National Institute of Agricultural Engineering.
Meeting to be held at The George Hotel, Huddersfield, Yorks

THE HARVESTING & MECHANICAL HANDLING OF VEGETABLES FOR PROCESSING

by A. J. GANE CDA, FRMS, FRSA*

Presented at the Annual Conference of the Institution in London on 12th May 1966

SUMMARY

The mechanical shelling of peas may be traced from the last quarter of the nineteenth century to the present day, throughout which period the principle employed has remained unchanged. The machines themselves have become increasingly sophisticated, firstly in the high degree of mechanization which has been achieved in harvesting and in the operation of the viner site, and more recently by the use of mobile viners which still further reduce the demands made on labour. The pattern of future developments may be suggested by the pea pod picker.

The mechanical harvesting of dwarf beans has become established much more recently and although a high degree of efficiency has already been reached it appears that changes are likely in cultural techniques and consequently in harvester design. On the basis of present evidence it would appear that the combination of narrower rows, higher plant populations and multi-row harvesters will increase both yield and harvester efficiency.

I. INTRODUCTION

While there is an increasing range of vegetables marketed as processed foods, peas remain by far the most important; the acreage of vining peas grown in this country has multiplied ten-fold in the last thirty years, and it has doubled in the last decade, nearly 80,000 acres being devoted to this crop in 1965. It is probably because of the considerable acreage involved, the importance of the time/quality factors in harvesting and the perishable nature of the product that a higher degree of mechanization has been reached than with the harvesting of most other vegetables.

The mechanical harvesting of dwarf beans has become common practice in the United Kingdom only in recent years, rapidly changing the crop from one mostly confined to the market grower to one which is now grown on a large agricultural scale. In the period of 1956-1965, the acreage of dwarf French beans rose from 2,400 to nearly 8,000.

A high degree of mechanization has been achieved in the harvesting and handling of both crops and although there is still room for further development in this field, lessons have been learnt which may well be useful in the general application of techniques of mechanization to other crops in the future.

II. THE HARVESTING & MECHANICAL HANDLING OF PEAS

Maturity assessment

The maturation of peas is a continuous process and since it is the aim of the packer to market a product of consistently good quality, it follows that ideally each individual sowing of peas should be harvested at the same stage of development. On a reasonably small scale, and for a comparatively limited period of time, a fair degree of accuracy may be achieved in this respect by the experienced eye, but where extensive acreages are involved throughout a campaign of five or six weeks duration, it is clearly desirable that there should be a reliable standard to which reference can be made.

There are accurate methods of assessment based upon changes in the chemical composition of peas; the percentage of alcohol insoluble solids, such as starches, hemicelluloses, fibre and protein, reflects the degree of maturity that has been reached. Such methods are too time consuming for every day practical use, but they do provide a valuable standard by which to determine the accuracy and reliability of the instruments now universally adopted for the assessment of maturity.

It was in 1937 that Martin introduced an apparatus, the tenderometer, to measure the force necessary to shear peas between two grids, and he found that it gave consistent results.

The essential part of the tenderometer consists of two series of metal shearing plates; they are mounted on a common shaft, and when in the 'open' position the edges of one set of plates are horizontal and the other vertical. A sample of peas is poured into the chamber thus formed, and when the lid is closed the vertical plates move downwards between the horizontal plates, shearing the peas as they do so. The lower grid is attached to a shaft equipped with counter weights, and its movement is transmitted to a pointer which indicates the 'tenderometer reading' on a scale above the machine. The tougher the peas, the greater is the shearing force required, and the greater also is the degree of movement transmitted to the pointer. In practice, peas for quick-freezing are usually required at tenderometer readings between 90 and 110 whereas for canning readings of about 100 to 120 are accepted.

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The standardization of tenderometers has proved to be a difficult problem, and no satisfactory artificial material has yet been found for the purpose; at the present time standardization is effected by means of synchronized testing against a master instrument, using specially prepared samples of peas.

A number of other instruments have been produced for this purpose, such as the maturometer and more recently the shearpress, but these have not been adopted commercially in this country at present. The tenderometer is a costly and heavy instrument, and there is as yet no satisfactory portable equivalent of sufficient accuracy.

Cutting and loading

It is only in the last twenty-five years or so that machines have been developed with the prime purpose of cutting peas. Hitherto, sail-reapers and mowers, sometimes with modifications of one sort or another, were used to cut the crop, but the task was a comparatively tedious one; especially in view of the weed population which so often infested peas at that time.

The torpedo pea cutter was one of the first machines introduced; it consisted of cone-shaped dividers mounted ahead of the tractor wheels, and V-shaped blades, mounted at the rear, which severed the pea plants just below soil surface. During and shortly after the last war, when machinery was scarce and costly, these torpedo-cutters did valiant work; they had a minimum of working parts, and they were driven at considerable speed, on the lighter and level fenland soils. Perhaps their greatest disadvantage was that as the blades moved through the topsoil, they threw up stones and earth which lodged in the swathe and eventually found their way into the sample, necessitating expensive cleaning and picking of the produce.

The arrival of the first pea cutter-swather from the U.S.A. heralded the greatest advance in pea cutting to date. These machines consist essentially of a cutter-bar, fitted with spring loaded fingers, above which is a fully adjustable bat and tine reel; behind the cutter bar is a windrowing canvas, which deposits the cut crop in a swathe to one side of the tractor, or less commonly there are two contra-rotating canvasses which deposit the haulm centrally, between the tractor wheels. The machines are rear-mounted, the tractor being driven in reverse from an additional seat; this gives the operator an unobstructed view of the cutter, maximum manoevrability and added traction.

Practically all vining peas and dried peas are harvested by machines of this basic design today.

The manufacturers of mobile viners have withstood the temptation to incorporate cutter bars in their machines. Difficulties can be experienced in the field in both cutting and vining respectively, and the very nature of the campaign is such that it would be unwise to jeopardise the progress of either operation through some minor mishap in the other.

Once vining peas are cut, they must either be loaded onto trailers or lorries and removed to static viners or they must be shelled direct from the swathe by mobile viners. Loading too has now become completely mechanized. Clean, rapid and yet gentle loading is essential, and is effected by green crop loaders incorporating slatted endless belts or cranked and tined mechanisms. Such loaders are tractor drawn, some depositing their load into a trailer hitched directly behind, while others discharge to one side into independently driven vehicles. While either type is suitable for use with high-sided trailers, sideways delivery is a considerable advantage where large lorries are in use as they allow the material to be deposited at any point throughout their length, thus reducing manual stacking to a minimum.

The use of high-sided tipping trailers has increased markedly in recent years, with the introduction of mechanical feeding devices to many static viners.

Pea vining

The principles involved in vining as we know it to-day, were first embodied in the pea sheller invented by Madame Faure, details of which were first published in Paris in 1885. Then, as now, the machine consisted essentially of an oblong frame in which revolves a hexagonal drum, the sides of which are formed by perforated 'screens' or 'mats', which are nowadays made of rubberized canvas or nylon. The drum is supported by rollers at each end and is revolved by means of a pulley. Arranged obliquely along an axle concentric with the drum are oblong beaters which pass close to the bars which form the angles of the drum; the axle revolves in the same direction as the drum, though at greater velocity.

Beneath the drum is an inclined endless apron, which revolves continuously; this apron was originally made of canvas and later of strips of aluminium, but rubberized canvas is now generally adopted.

On feeding peas into a viner drum, the action of the beaters opens the pods, the peas and small waste fall through the surrounding mesh and onto the inclined apron beneath; the angle of the beaters propels the bulk of the haulm to the end of the drum, where it is discharged. The peas roll down the inclined apron, whereas the small waste is elevated by its upward movement.

The hand operated machine of 1885 was designed to shell peas from pods previously picked by hand, but developments continued in France, in America and elsewhere, and soon after the turn of the century machines were produced which shelled peas from the entire haulm.

Such refinements as feed and waste elevators were soon to follow, but improvements in vining efficiency were still to be made. The speed at which the beaters must strike in order to shell the peas depends largely upon the toughness of the pods, but in the older varieties of peas in particular, there is a considerable difference in the maturity of pods on any one plant. The lowest pods may be well filled and tough while the upper ones are young and tender, containing soft peas which are easily damaged. No one beater speed, therefore, can give the desired result with such material.

In order to overcome this problem, the beater drum is now progressively tapered throughout its length; the peripheral speed of the beater blades therefore increases as the vine proceeds through the drum. Tender pods are thus burst open soon after entering while tough pods may not be struck with sufficient force until they are approaching the discharge end; there is therefore provided in this single operation a progression of beating vigour, so that the toughness of each pod is catered for.

The pursuit of greater efficiency led to the introduction of a variable speed gear in the drive sequence, and by this means the severity of the blows delivered by the beaters can be adjusted to achieve maximum extraction with a minimum of damage.

Having reached this stage of development, the efficiency of shelling is generally very good indeed, although difficulty may still be experienced with some varieties. Kelvedon Wonder, for example, has a habit of producing pods which are hard to open, and if adjustments are made in order to achieve complete shelling then the more tender peas in the sample are likely to be severely damaged. There are occasions, therefore, when one has to compromise and settle for the maximum extraction of undamaged peas.

Varieties with very pointed pods are to be avoided, as they are generally very difficult to shell efficiently.

Adjustment of the viner in order to give the maximum recovery of shelled peas is not difficult. At the beginning of the season, when crops should be relatively immature, a beater drum speed of about 160 rev/min and a beater angle of about 10° is a good starting point. If excessive damage is done to the peas at this setting, then the beater angle must be increased in order to reduce the time spent passing through the drum and drum speed may be reduced also in order to lessen the severity of the blows received by the pods.

If on the other hand an excessive number of pods is found to be passing through the drum without being shelled, the opposite course must be adopted.

Such adjustments are easily made while the machine is in motion.

Both the shelled peas and the exhausted haulm should be inspected at frequent intervals, as the state of the crop can vary markedly even within the same sowing, and if efficiency is to be maintained the necessary adjustments must be made.

A high degree of mechanization is now possible. The feeding of vine into the machine, previously carried out by hand, can now be effected by hydraulically operated grabs, one man being able to feed two viners with such a device; the comparatively large quantities of haulm deposited on the elevator are teased out automatically by a feed regulator situated at the mouth of the drum. The use of grab and regulator has made it possible to dump loads of vine from tipping trailers, whereas previously dumping created much difficulty for those feeding by hand as the haulm tended to roll and to be difficult to separate with forks. This practice has therefore greatly reduced the labour force necessary.

Only recently an alternative method of feeding has been introduced to this country from the United States, where it has been in use for some years. The standard feed elevator is entirely replaced by a large hopper, in the bottom of which is a slatted conveyor chain, on the muck spreader principle. Incorporated in this device are controls which automatically regulate the speed of the flow of vine into the drum.

The hopper is fed by foreloader, with vine dumped in the vicinity from tipping trailers. The use of such a system drastically reduces the labour requirement, since one man and his foreloader can feed four viners, whereas in the case of hand feeding, at least eight men would have been needed. Not only has it become very expensive to employ large gangs of men for such work, but it has become increasingly difficult to find sufficient men of the right type for the vining season.

Additional saving is effected by virtue of the fact that throughput at the viner is continuous, and also the turnround of vehicles is speeded up as their loads are dumped on arrival and there is no waiting involved.

Much hard work has also been obviated through the introduction of waste conveyors. A small endless belt collects the waste chaff from the top of the main apron, depositing it on the main waste conveyor which in turn collects the exhausted haulm from a number of machines and elevates it into a waiting vehicle for removal from the site.

The labour required in handling the peas themselves has also been minimized. At one time, they were collected by a hopper placed in front of the main apron; by removing slides at the base of the hopper they were fed into wooden or metal boxes, each containing about 28 lb of peas, and each requiring manhandling in filling, stacking and eventually in loading for transporting to the factory.

The peas are now collected by a bucket conveyor lying between the aprons of a left-hand and a right-hand viner, and are discharged into galvanized tanks of 8 or 10 cwt capacity, which can be loaded by fork lift truck or moved on their own wheels to a further process line.

This mechanization at the viner sites has greatly reduced the labour force necessary and in addition it has improved throughput and general efficiency.

The cleaning of vined peas

During vining itself, the action of the beaters upon pea pod, stem and leaf—and upon any weeds present—releases juices which are likely to adhere to the surface of the shelled peas, and which may cause off flavours in the product. In addition the removal of small waste by the main apron is seldom complete, so that fragments of weeds, haulm, soil and stone may be mixed with the sample.

The admixture of soil is generally greatest in wet harvests, when the haulm gets muddy during cutting and loading; leaf fragments are most troublesome in hot and windy conditions, when they are often blown from the main apron into the bucket elevator collecting the vined peas.

While all peas are of course cleaned on arrival at the factory, it is generally accepted that it is advisable to carry out primary cleaning immediately after vining and before undesirable jucies have soaked in or dried, thereby making their removal difficult if not impossible. To this end, peas are first conveyed by a gooseneck bucket elevator into a combined winnower and sieve, which removes the light fragments of trash by means of a contra-flow air stream, and then separates the peas from large and small waste respectively by means of shaker screens.

The peas then pass into a flotation washer, where they first meet an upward flow of water which conveys them forward but which allows any stones or grit to sink; they then enter the flotation section, in which sound peas sink but damaged peas, pod, leaf and stalk fragments float over a weir to waste. Finally the sound peas reach a further shaker unit, where they are rinsed by a fresh water spray.

Some viner sites are situated at considerable distances, from the parent factory, and in order to minimize deterioration in transit peas are often cooled before despatch. The principle usually employed is to immerse the peas in water which has been cooled, either by pumping it through a container filled with ice or through an automatic refrigeration plant. In either case the peas are fed into the cooled water, and together they are pumped through a cooling tower consisting of two concentric tubes; over a grid which separates the water from the peas and into waiting tanks.

While it has been suggested that there are important losses from the leaching which takes place in such a system, and that peas should be kept dry until immediately before processing, this method remains the most common, although dry cooling has been adopted in some instances.

The grower is paid for 'vined, cleaned' peas, and so it is at this point, after passing through the winnower and flotation washer, and where necessary having been cooled also, that an automatic weigher can be incorporated in the line. The practice followed varies between companies. In some instances there are cleaning lines at both viner site and factory with automatic weighing at either, while in other cases no cleaning at all or merely a riddling is carried out at the site and all other cleaning and weighing is done on arrival at the factory.

Static viners

Until comparatively recent times viners were situated either at the processing factory or on farms quite close to the factory. In either case the machines were almost invariably the property of the processor. The majority of those on farms were placed singly or in pairs, and the bulk of the peas to be vined were grown on the same holding. Latterly there have been two important trends away from this system. Firstly some processors have favoured the grouping of viners into units of eight to thirty or more, since by so doing they can economize in the provision of the necessary services and exert a higher degree of supervision and control than is possible with numerous scattered sites. Resident mechanics, with stores and equipment to hand, can clearly provide a quicker and more complete service than could be afforded from the mobile workshops previously employed. Through the regular inspection and maintenance of plant and machinery made possible by such a method, minor faults are often corrected before they develop into actual breakdown, with an invaluable saving of time. Transport too is clearly more economically employed when collections are centralized.

Secondly, a number of growers now contract to supply their processors with vined peas, and in order to do so, they provide their own viners and ancillary equipment. The capital investment required is high, and to operate efficiently a reasonably large acreage of peas is required.

It is in the light of these considerations that a number of co-operatives have been formed by groups of growers, who jointly provide the capital not only for the vining equipment but for harvesting machinery too. Team work of this nature enables each member of a group to have the benefit of equipment which in many cases he could not justify in relation to his individual acreage, or which would in any case be far less economic when confined to his acreage alone.

In view of the investment called for, it is usual for such co-operatives to be offered a long term contract, rather than an annual one.

Mobile static viners

'Mobile static' viners can be very valuable in certain circumstances. They are, of course, normal static viners suitably mounted on wheels so that they may be towed from place to place, but remain stationary for vining purposes. Machines of this sort have the advantage that in cases where peas are grown over a large area, it is possible to gradually move a team of viners northwards, thus extending the processing season without the additional capital cost of extra machines.

Mobile viners

A major cost in the operation of static machines is to be found in the loading and transportation of the entire crop to the viner site, coupled with the removal and disposal of exhausted vine. With an average yield of peas-plus-haulm in the region of ten tons per acre, it is not surprising that the engineer should have looked with envy at the combine harvester of the corn field, and turned his thoughts to the possibility of emulating such a method for peas.

There are now a number of machines on the market which are designed expressly for this purpose. One manufacturer in the U.S.A. estimates that if present trends continue, all peas there and in Canada will be harvested with mobile viners by 1968. Thirteen hundred of their own mobiles were in operation in the States in 1965.

All mobile viners call for previous cutting and windrowing of the crop, which is then collected by means of a pick-up reel and elevated to the drum. In order to operate efficiently the drum must remain as nearly horizontal as possible, and in view of the terrain over which such machines must work, an automatic levelling device is incorporated.

Although alternatives have been the subject of experiment, the mechanism responsible for the shelling process remains the same as that already described. Chaff is separated by the inclined endless belt and pea recovery mechanisms operate at the discharge point, in order to retrieve peas lodged in the vine. Some machines also incorporate a pneumatic waste separator for the further removal of chaff.

The shelled peas are lifted by bucket elevator to a storage tank, where they await collection, which can be effected either by removing the full tank and replacing it with an empty one, or by some form of dumping hopper which merely off-loads the produce into a tank brought alongside.

The exhausted vine can be deposited in a windrow behind the machine for later collection and ensiling, or when it is not required for this purpose attachments are available which spread the material to facilitate subsequent cultivation.

At the present time, the majority of mobile viners are tractor drawn and although self-propelled models are apparently becoming increasingly popular in the United States it seems debatable whether or not the additional cost is justified. Unlike cereal combining, the cutting of the pea crop is likely to remain a separate operation, and consequently the difficulties experienced in the 'opening out' of corn fields by offset tractor drawn machines do not arise. While it is of course true that the more compact self-propelled viner would effect some saving through improved manoeuvrability, and that contamination of the windrow with soil from the tractor wheel in wet weather would be eliminated, it seems doubtful if this is enough to warrant the increase in capital investment involved. Where steep hillsides are to be negotiated, the self-propelled unit does have a distinct advantage, but there are few such areas in the pea growing districts of this country.

In the early stages of development grave doubts were frequently expressed concerning the ability of a 6 ton machine to operate in wet conditions, but it was soon found and is now generally accepted that mobile viners can keep going as long as the cutter-windrowers which precede them. The machines have large wheels, and are so designed as to transfer much of their load to the tractor drawbar, thus increasing traction.

Peas collected from mobile viners may be transported direct to the factory, or they may be first taken to a central depot for cleaning and cooling purposes, depending upon the distances involved in individual cases.

The influence of mechanical harvesting on cultural techniques

The efficient use of cutter-windrowers, loaders and mobile viners is facilitated by the provision of a firm, level and stone-free surface, so that one-way ploughing is to be preferred, and on stony land, the final cultivation should be rolling. An uneven surface presents difficulties in that the fingers and cutter bar tend to dig into the ground at times, thus increasing the contamination of the haulm with soil and stones, while large stones left on the surface clearly endanger the cutter bar, increasing breakages and the time loss involved.

Weed control is very important from a number of points of view, but as far as harvesting is concerned the presence of excessive weed growth makes cutting more difficult, it wastes valuable trailer space and vining time, and in the case of some weeds in particular, such as chickweed, the risk of soil in the sample is again increased. Some weed stems break up into short lengths during vining, while others such as 'runch' shed their seed pods; these fragments can be most difficult to separate out, and can severely reduce throughput by clogging cleaning machines. Others such as wild oats, produce an enormous bulk of material, and choking of the viner may result. Weeds such as mayweed and poppy have flower 'heads' of similar size and density to peas, which consequently pass through the winnower, the riddle and the flotation washer without being separated from the peas themsleves. Contamination of this nature is a serious matter, since removal must be effected before the produce is processed, and where machinery cannot adequately achieve it the only alternative is hand picking. This is not only a costly operation, but during the height of the season when a factory is in full production, it is seldom possible to give a particular lot of peas this 'individual attention'. Weeds not only reduce the return of the grower through competition with his crop, therefore, but they increase his harvesting costs and they may even result in the rejection of his crop for processing purposes. Great strides have been made in recent years with the provision of improved materials and techniques for weed control in peas,[1 2] although research is continuing in order to achieve still greater efficiency.

The row width in which peas are grown also affects the efficiency of cutting, since when peas are grown in very wide rows, as was common practice some years ago, the plants tend to become laid to such an extent that they may be cut in more than one place and pods are liable to be cut off or dropped. Recent research[3] has indicated that the optimum row width for peas lies between four and eight inches, however, so that this problem is likely to be of little importance in the future. A wide range of plant populations was also studied in the work referred to above; eleven plants per square foot appears to be the optimum, and at such a population the peas generally stand up well and present upright stems to the cutter.

Extensive studies of varieties of vining peas have also been in progress for some years,[4] in which hundreds of varieties have been carefully examined in relation to agronomic characteristics and quality. From the point of view of harvesting and handling, the quantity of haulm produced is a greater limiting factor than the yield of peas, and therefore high yielding varieties providing good quality produce, but on reasonably short vine, are in demand while the older varieties, many of which were bred for garden use, are being replaced as quickly as possible.

The control of pests is also important, not only because of yield losses which might be involved, but because contamination may occur. The pea aphid, for example, may not only reduce yield and transmit virus diseases but its secretion of 'honeydew' appears as a sticky coating on vining equipment, reducing its efficiency and making thorough cleansing of the machinery very difficult. The pea moth maggot, on the other hand, damages individual peas within their pods, and again the processor may be obliged to reject crops in which such damage is found. Similarly, some fungus diseases such as leaf and pod spot, downy mildew, a deficiency disease such as marsh spot, or a physiological disorder such as yellows or 'blondes', may result in rejection, simply because the removal of the imperfect peas from the sample is not practicable, and because standards of quality in the pack must be maintained.

The growing of peas for mechanical harvesting and processing therefore calls for the greatest skill and care. The vast majority of the risks involved under this heading may be avoided or adequately controlled by the grower who is prepared to take full advantage of up-to-date knowledge and techniques.

Future developments

It is well known that as soon as peas are cut, deterioration begins, and that as soon as they are vined this process of deterioration is greatly accelerated. It is therefore logical to suggest that if peas could be picked in the field, but not shelled until arrival at the factory, the great reduction in the time spent between shelling and processing would result in a product of superior quality.

To consider a return to hand picking, over the vast acreages now involved, is of course unthinkable, but a mechanical Pea Pod Picker has been undergoing development for some years now, and according to the latest information from the manufacturers it is expected to be on the market in 1967 or 1968. This self propelled harvester has an eight foot cutter bar over which operates a reel, taking the peas back onto a slatted elevator which conveys the vine into the heart of the machine. Here the vine is cut into short lengths, the pods are separated pneumatically, and the exhausted vine is discharged.

There is storage capacity on the machine for 2,500 lb of peas plus pods, which can be off-loaded by elevator while the podder is in motion.

Whether or not this is the ultimate pea harvesting mechanism, only time will tell, but it will at least prove to be the subject of a chapter yet to be written in the story begun by Madame Faure, over eighty years ago.

III. THE HARVESTING & MECHANICAL HANDLING OF DWARF BEANS

Maturity assessment

As in the case of peas, the processor of dwarf beans is anxious to obtain a pack of consistent quality and therefore aims to harvest all crops at about the same stage of maturity. Over-maturity is typified by such factors as an excessive proportion of fibre, 'bumpiness' of the pod, 'cavitation', seed development and the production of 'string'. Tests have been carried out to determine whether or not the relationship between seed and pod length, or seed and pod weight, afford accurate means of assessing maturity, and it has been claimed that the shearpress is capable of assessing beans in a similar manner to that in which the tenderometer assesses peas.

Dwarf beans remain suitable for processing for quite some days and during this period there is no untoward deterioration in quality, although yield increases rapidly. It is therefore most important that the crop should be harvested at just the right stage if the maximum return is to be obtained, and it is to be hoped that further research will provide a means of recognizing that stage under field conditions.

Harvesting

Mechanical harvesting of dwarf beans, which are also often referred to as 'snap' or 'bush' beans, is a much more recent innovation than in peas. A rapidly expanding market for this vegetable in canning, dehydration, and quick-freezing, coupled with increasing difficulties as regards cost and availablility of suitable hand labour, resulted in experimental work being started with prototype harvesters in New York State in 1951. At this time the cost of hand picking often accounted for more than half the value of the crop. The commercial production of harvesters began in 1956, and acceptance of the machines was so rapid that it was estimated that two thirds of the crop in New York State, some 20,000 acres, was mechanically harvested in 1958.

The basic principle involved in harvesting mechanically is said to have originated with a grower who observed his wife swing a garden rake up through a row of beans and remove a number of pods in the process. It was from this that there developed the use of a steel-fingered picking reel, mounted around an axle rotating lengthwise to the row. Pairs of these reels were mounted on either side of a conveyor belt and were inclined in such a way as to pick the upper pods first and then pick progressively lower as the machine advanced along the row.

The stripping action of the reels removed not only the beans but the foliage too, so that once this operation had been carried out further growth could be discounted.

Owing to the finality of mechanical harvesting, some growers who still had labour available would reserve the machine for a second picking, following a first harvest carried out by hand, but it was soon found that the yield and quality of the produce at the second harvest was inferior and the practice soon declined.

Experiments indicated that while a carefully operated machine could pick as high a proportion of the crop as hand pickers, the yield from two or three manual harvests was greater than from a once-over mechanical harvest. The problem of obtaining sufficient hand labour remained however.

As regards quality, it was found that the machines picked a higher proportion of small beans than did most human harvesters, that many beans arrived at the factory in clusters, and that some beans were bruised by the steel fingers and that in consequence only a few hours could elapse before processing without marked deterioration. The machine also picked up soil and stones, especially where ridging had occurred as a result of inter-row cultivation.

Bean harvesters today

The original American machines harvested two rows at a time and required inter-row spacing of thirty-two or thirty-six inches; this basic design is still in use in the

United States, whereas in European countries such row widths are generally uneconomic and single-row harvesters requiring row widths of only sixteen or eighteen inches have generally been adopted.

The first British machine was marketed in 1962, after five years of development. The machine was tractor mounted, the single-row picking mechanism being at the front of the tractor and a pneumatic trash separating assembly and bagging off point being at the rear, with an elevator and conveyor system linking the two. More recently this machine has been entirely re-modelled to form a tractor-drawn unit.

In this respect it is interesting to note that a survey[5] of fifty-seven farms in New York State in 1962 showed that forty-three of the farmers owned bean harvesters and that all but three of them were tractor mounted.

At the present time the produce is packed in a variety of containers for transporting to the factory, such as sacks, net bags or small wooden boxes. It has already been found in the United States that considerable savings in labour costs can be effected by the use of pallet boxes, and in this country the eight or ten hundredweight tank is now accepted for peas. It is hoped that we shall take rather bolder steps in effecting mechanization in such fields as this, rather than following the piecemeal development so often illustrated.

Quality

The quality of the produce can be affected to some extent both by the method of picking and the type of container used. Mechanical harvesters generally pick a higher proportion of the smaller beans thus increasing the value of the sample from this point of view.

Unfortunately, however, many beans are bruised by the steel tines, and those remaining in clusters must be separated before processing. Some beans are broken but nevertheless remain among the whole produce; the juicy broken end may become stained, especially where harvesting is being carried out on peat soils.

Beans which are transported in bulk for long distances and without adequate ventilation are liable to deteriorate rapidly if some of their number are infected with certain diseases, such as grey mould (Botrytis spp.), anthracnose (Colletotrichum lindemuthianum) or a bacterial disease such as halo blight (Pseudomonas phaseolicola).[6]

The action of the reel tends to pick up soil and stones, particularly of course where inter-row cultivations have been carried out, and their removal from the sample can sometimes present problems.

The influence of mechanical harvesting on cultural techniques

As in the case of machines for harvesting peas, bean harvesters should be provided with reasonably firm and level ground if contamination with soil and stones is to be avoided. It follows, therefore, that inter-row cultivation must be replaced by the use of herbicides; experimental work is in progress[7], but no practical recommendations can yet be made for materials other than dinoseb-amine or dinoseb in soil, applied as pre-emergence treatments. Such treatments are by no means ideal, as the degree of residual activity is limited, but they are useful until such times as a herbicide becomes available for post-emergence use in this crop.

In view of the outstanding results which have been obtained through the study of spatial arrangement in peas[3], the influence of row widths and plant populations on dwarf beans was among the first subjects to be studied by the P.G.R.O. Experiments were designed with both long term and short term aims, firstly, to find the optimum spatial arrangement for dwarf beans, and secondly, to find the optimum plant population for dwarf beans grown in the row widths demanded by existing harvesters. This work is still in progress, but the indications are that high populations and row widths narrower than those in use at present will prove to be more profitable.[7]

The likelihood of this was forecast by the P.G.R.O. some three years ago, and machinery manufacturers were advised to think in terms of developing harvesters which could deal with a complete swathe of beans, virtually irrespective of row width, rather than only one or two rows at a time. Clearly there were considerable mechanical difficulties, but there is now every reason to suppose that they will be overcome.

The use of high plant populations, evenly spaced, will help to suppress weed growth; this in turn will increase the number of herbicides which may be suitable for use in the crop, since there may well be some materials whose efficiency is adequate in conditions of intense competition, but which are inadequate in its absence.

High plant populations might be expected to increase the incidence of disease, but there is as yet no evidence of this in dwarf beans; if it does appear to be a factor of importance then efforts must be redoubled to provide prophylactic treatments to overcome such difficulties.

The choice of variety can greatly influence the efficiency of harvesting, since a number of agronomic characteristics have a bearing on the performance of the machines.

From the point of view of mechanical harvesting alone, a dwarf bean plant should not greatly exceed fifteen inches in height, it should be of compact and erect habit, standing upright and bearing its produce as near to the top of the plant as possible. A reasonable amount of foliage is desirable, as it protects the beans from being bruised by the harvester tines, and on very light soils good root structure is necessary in order to resist their combing action.

In addition, beans for processing should be reasonably straight, oval or round in cross section, of uniform colour and of good flavour; they must yield well, being slow to develop seed and 'string', and must mature evenly. The pods must be held clear of the soil in order to avoid spoilage from *Botrytis sp.*

Many varieties of dwarf beans have been assessed in P.G.R.O. trials in recent years, and the vast majority have the characteristics required for mechanical harvesting.[7]

Future developments

There is a marked similarity between the growth of the dwarf bean industry at the present time, and the events which so greatly influenced the pea industry some twenty years ago. In both cases the increasing importance of the crop has resulted in greater effort being made in applied research. In both cases a crop traditionally grown in wide rows and kept clean by cultivation has been found to benefit from closer rows and higher populations, with the result that chemical weed control becomes essential. As this pattern unfolds, it is evident that multi-row harvesting of dwarf beans must follow.

The production of weed-free dwarf beans, grown in their optimum spatial arrangement, and harvested mechanically, is likely to be one combination of developments which will markedly influence the future of this crop.

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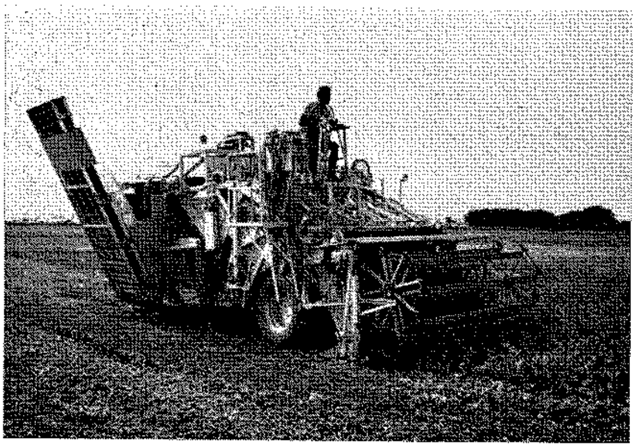

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Fig. 1—The pea pod harvester

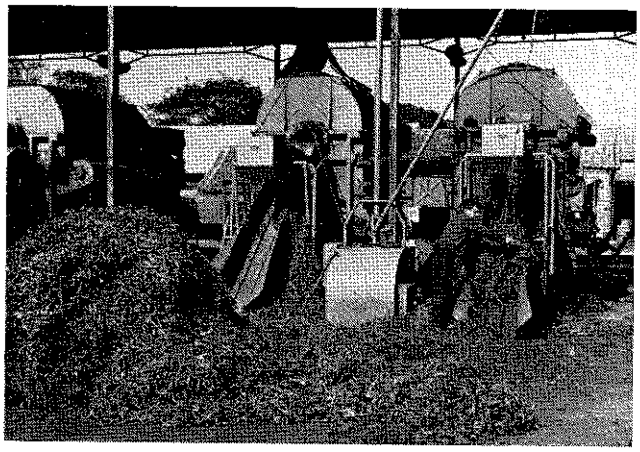

Fig. 3—Feed hoist and feed regulators in use

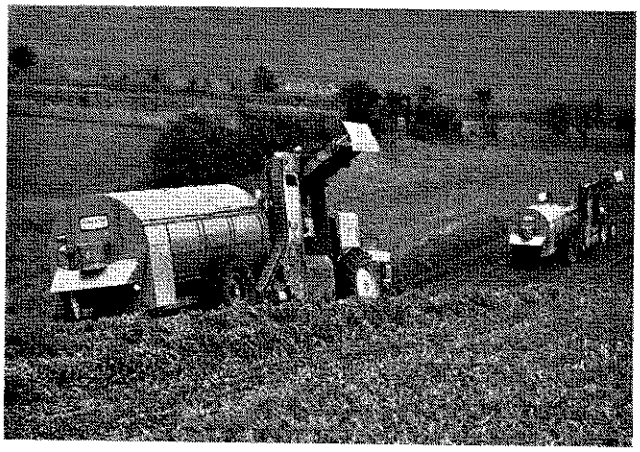

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Fig. 2—Mobile pea viners

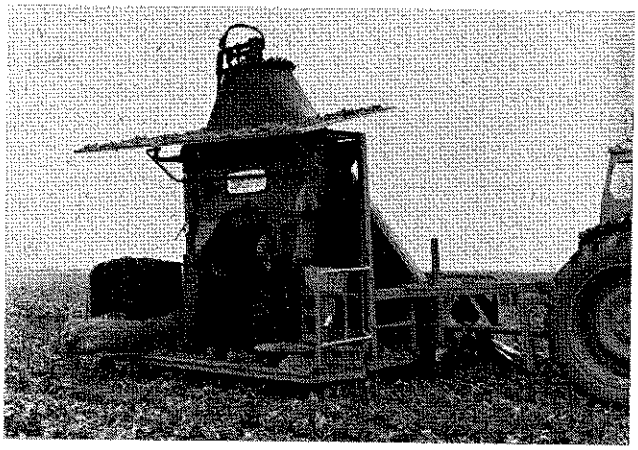

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Fig. 4—Dwarf bean harvester

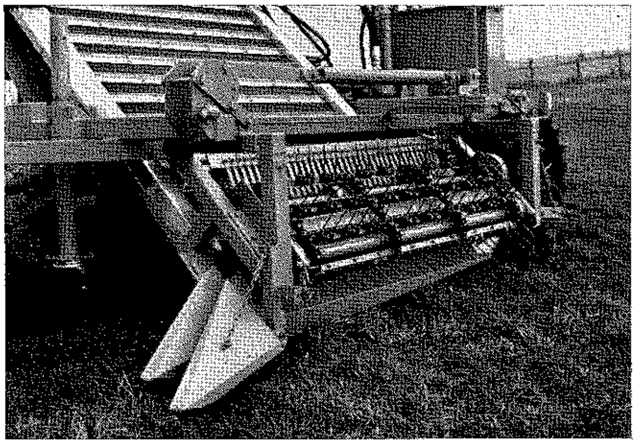

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Fig. 5—Bean picking reel

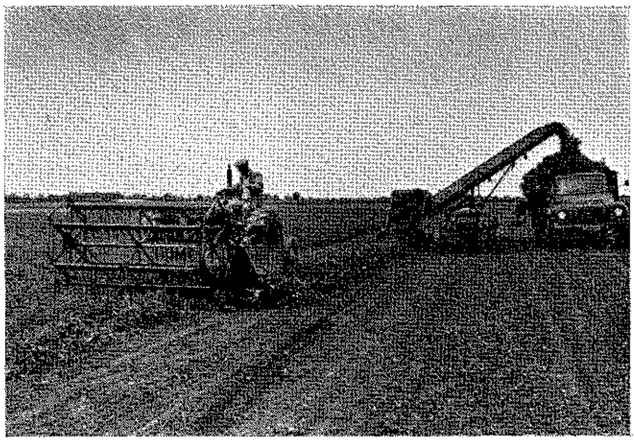

Fig. 6—Cutting and loading vining peas

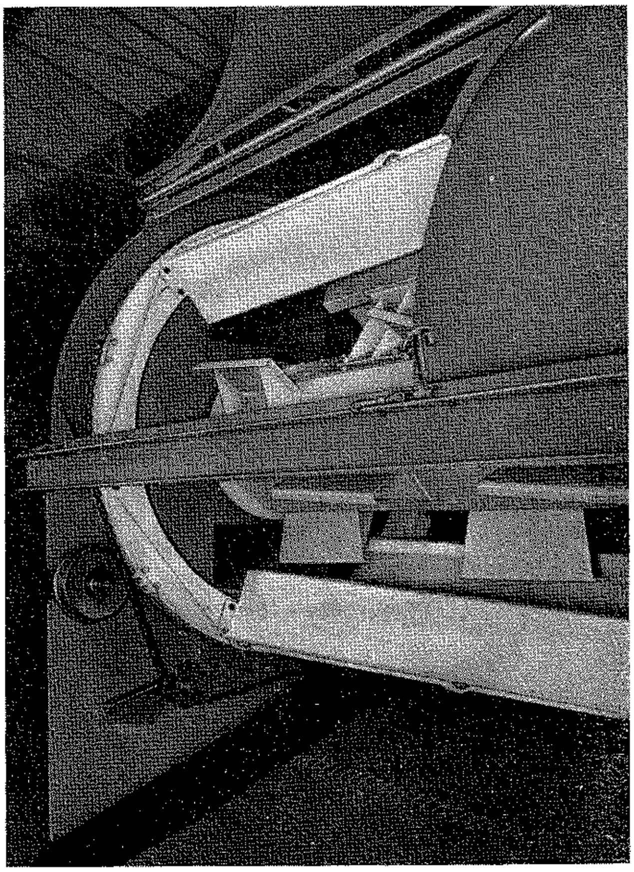

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Fig. 7—Static viner beater and riddle drum

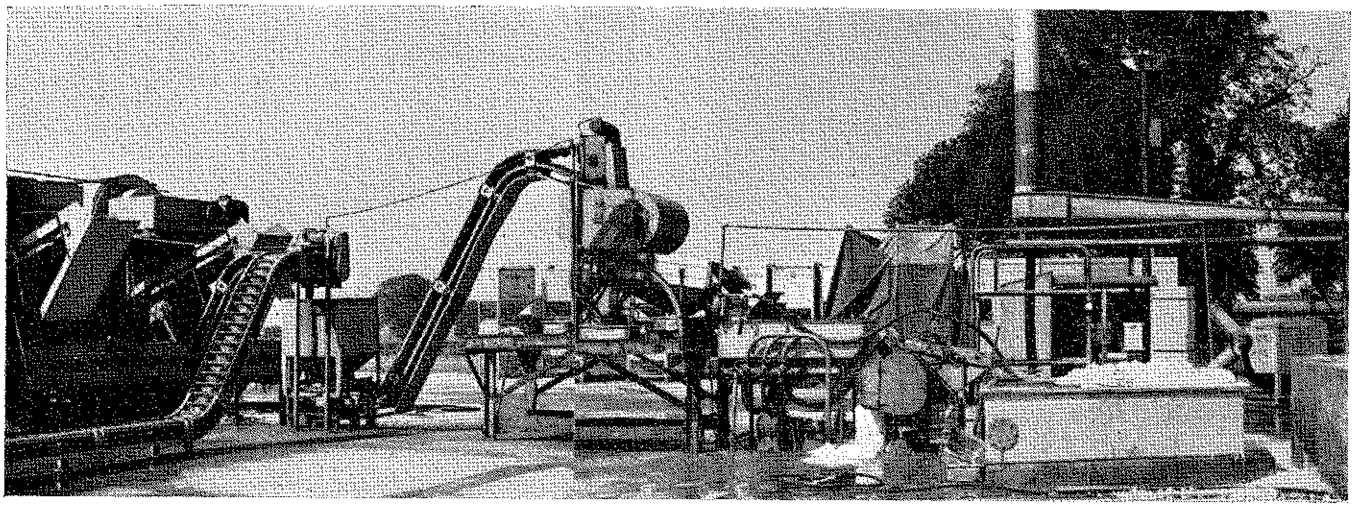

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Fig. 8—Static viner site, showing viners, bucket conveyors, winnowers, flotation washer and cooling system

Discussion to Papers by J. C. Hawkins and A. J. Gane

MR E. S. BATES (British Petroleum Ltd) complimented the authors of the two papers that had just been presented. He asked Mr Gane how many gallons of water were required for every finished product and to comment on the effectiveness of detergents in the washing of peas and other products in removing the sticky materials referred to.

MR GANE replied that he had no information on throughput of water for washing. Some detergents had been used in the past, not so much to improve the washing itself but rather to reduce the amount of froth produced in the process. This could be a great nuisance on viner sites because the water used in the washing process collected a considerable amount of juice and material from the peas themselves; the resulting froth could flow all over the site. Detergents had been used to reduce the production of this froth quite successfully.

CAPT. E. N. GRIFFITH (Rotary Hoes Ltd) said he would like to make some comments based on his own farming experience. He recalled an instance when he had five large harvesting machines actually in use in one field at one time; this represented a capital investment of about £45,000 in one field. These handled the peas so rapidly that the processing factory broke down and he was left with all his peas. He had tried to transport them to other factories in the Eastern Counties but once the peas were in their trays, the deterioration was so quick that they would not stand up to the transport; this emphasized the point that if peas were threshed in the field, one was very limited as to the area in which they could be grown. It must be within a very short distance from the factory.

The new method of harvesting the pea in the pod should very much extend the area that a factory could cover. In Common Market countries, the type of pea which was appreciated there was the French 'petit pois' and Capt. Griffith asked if this type lent itself to mechanical handling.

Mr Gane replied that there was no doubt at all that the introduction of the pea pod harvester would increase the area from which peas could be accepted by a canning or freezing factory. The situation could be further improved by the cooling method which he had mentioned in his paper. One could, for example, even in the hottest weather, cool peas sufficiently to enable them to be transported forty or fifty miles to the factory and it must be appreciated that such a radius represented a considerable acreage; pea pod harvesting would certainly do much in this direction. The machine would certainly deal with 'petit pois' as could any of the existing machines, given some minor adjustments. On the basis of a study of varieties however, Mr Gane felt that the greatest drawback would be the disappointingly low yields compared with those to which one had become accustomed from the varieties grown today.

MR M. COFFEY (Irish Sugar Co. Ltd) said he would like to put several questions to Mr Gane. Firstly, why had nobody gone to any trouble to invent a combined cutter and loader? Secondly, why were stationary viners so

(*continued on page* 110)

A UNIVERSAL VEGETABLE HARVESTER

by W. BOA, BSC(AGR), NDA, AMI AGR E*

Presented at the Annual Conference of the Institution in London on 12 *May* 1966

I. INTRODUCTION

A universal vegetable harvesting machine likely to be applicable to a large enough number of growers to make it acceptable for manufacture and sale on a national rather than a local basis must be simple and inexpensive. It must also be light in weight so that it can be worked in winter conditions. It follows therefore that the machine can only employ the once-over destructive method of harvesting.

For wide application, however, the machine must be capable of dealing with a range of very different crops; reference to Table I in Mr J. C. Hawkins' paper 'The Mechanization of Vegetable Harvesting' shows that a machine which cannot deal with carrots, Brussels sprouts and cabbages cannot be claimed to be universal. Carrot harvesting presents similar problems to the harvesting of red beet and turnips; Brussels sprouts are not very different from kale, and sprouting broccoli and cabbages can be considered to be similar to lettuces. It is also possible that summer and autumn cauliflowers may be suitable for destructive harvesting and they too can be grouped with cabbages. It follows therefore that a machine which harvests carrots, cabbages and Brussels sprouts successfully can be expected to have an application to at least 65% and perhaps 75% of the acreage of vegetables, excluding peas and beans, that are grown for human consumption and also that if any one of these three key crops is omitted, the percentage falls to 45% or less.

Cabbages, Brussels sprouts and carrots present such very different harvesting problems that it is difficult to imagine one machine harvesting all of them satisfactorily unless it is considered as a basic unit with additional attachments for various crops or groups of crops. Because simplicity and reasonable cost are also requirements of a universal vegetable harvester, its role in the harvesting process must be strictly limited. Throughout the development project which is described in this paper the harvesting machine was defined as a machine to cut or lift the crop, delivering it in an undamaged, uncontaminated but in some cases only partially trimmed state into a vehicle or container for transport to a packing shed or factory where it would be prepared to meet either the requirements of the fresh market or those for prepacking or processing.

* Cultivation Department, National Institute of Agricultural Engineering.

II. DESIGN OF THE BASIC UNIT

1. General Principles

Even a simple vegetable harvesting machine must carry out a number of distinct operations which vary with the crop. Thus with root crops the soil must be loosened, the crop must be lifted and freed from soil adhering to it, unwanted tops must be removed in conformity with market requirements and the roots must be elevated into vehicles or fed into containers. It is also desirable that damaged, malformed and diseased roots should be discarded.

Leaf crops must be cut at or above ground level to prevent contamination from soil and elevated into vehicles or, where the crop is particularly susceptible to damage, fed into small containers. It is also desirable that loose leaves should be removed, but it is very doubtful whether any crop should be trimmed on the machine unless it is graded and packed in market containers at the same time. With bulk handling which is necessary for high working rates, the outer leaves which would be removed for marketing act as a protective layer against damage during loading and transport.

Different harvesting operations are required for crops such as leeks and onions, but when all the requirements of a wide range of crops are analysed it is found that various combinations of a relatively small number of attachments cover all but a very small number of crops. It was on this basis that the N.I.A.E. Universal Vegetable Harvester was developed and throughout the work care was taken to ensure that attachments designed for one crop could also be used in combination with others required for different crops.

Probably the most important decision about the design arose from the fact that many vegetable crops are grown on expensive land where narrow headlands are usual: it was decided at the outset that the universal vegetable harvester should be tractor-mounted rather than trailed. Furthermore, because not all growers possess large tractors it was also decided that the machine should be capable of working on a relatively light tractor likely to be available on most holdings.

Tractor wheels cannot be run through crops like cabbages or lettuces which are best grown so that they cover the ground when they are mature and tall-growing crops like Brussels sprouts will not pass under the axles of a standard tractor without being damaged. The digging share or crop cutting assembly with their associated elevator therefore had to be mounted outside the tractor wheels and it was desirable for accurate steering that the share should be positioned between the lines of the front and rear axles. This arrangement had the added advantage that crops in a variety of row widths could be harvested without the need for changing tractor wheel settings (figure 1).

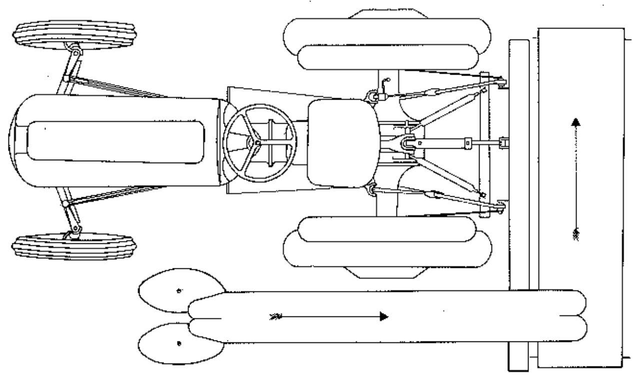


Fig. 1—Layout of Universal Vegetable Harvester

With this layout a hollow load-carrying beam across the rear of the tractor extending over the row to be harvested was the simplest type of frame to which all the various components and attachments could be fitted. Besides simplicity, the beam had the added advantage that drives from the tractor p.t.o. could be accommodated inside and around it with the minimum number of expensive guards. By locating the beam on the standard 3-point linkage it was also possible to free the tractor quickly for other work and to ensure that the machine could be used with any make of tractor of comparable power and weight.

The machine, however, could not be carried on the standard lift arms even when stabilizing bars were fitted because its out-of-balance weight was greater than that for which the lift linkage was designed. The hydraulic lift was therefore used only when coupling the machine to its tractor. In work the beam was carried on a pad built up from the drawbar and stayed from the rear axle casting. The lift arms were clamped firmly to this pad so that none of the weight of the machine was carried by the lift linkage. A double-acting hydraulic cylinder in place of the normal top link was used to tilt the beam about the lift arm pins, thus controlling the depth of working of the share or lifting it into a transport position. By making the top link bracket as a hinged unit with an easily removed locking pin it was also possible to allow the share unit to float freely following the ground surface and yet be lifted for transport. The portion of the machine overhanging the width of the tractor was positioned on the driver's left so that on narrow public roads hazard from on-coming traffic could be reduced by driving with the share assembly above the grass verge.

2. Shares

An experimental potato digger for plant breeders[1] which was developed in 1961 showed that a share made from a pair of driven flat discs, besides being very difficult to block at any forward speed in any crop conditions, had the virtue of having negligible draft. In this share a pair of 20 in. diameter plough coulter discs were mounted with an included angle of 140° and raked forward about 10° to give some lift. A gap 2 in. wide between the discs resulted in a narrow strip of soil not being cut, but no crop was lost through the gap. Trials in a stationary rig and in the field showed that the gap was necessary to prevent stones from wedging between the discs and that the only other important criterion in the design was that the surface of the discs should travel faster than the soil being fed onto them by the forward motion of the machine.

This share as designed for potatoes was obviously also suitable for shallow rooted crops like turnips, round red beet and onions, and it was reasonable to suggest that if the discs were set so that they touched or overlapped each other slightly they would cut through the stalks of leaf crops.

Discs set with an included angle of 140° could not be

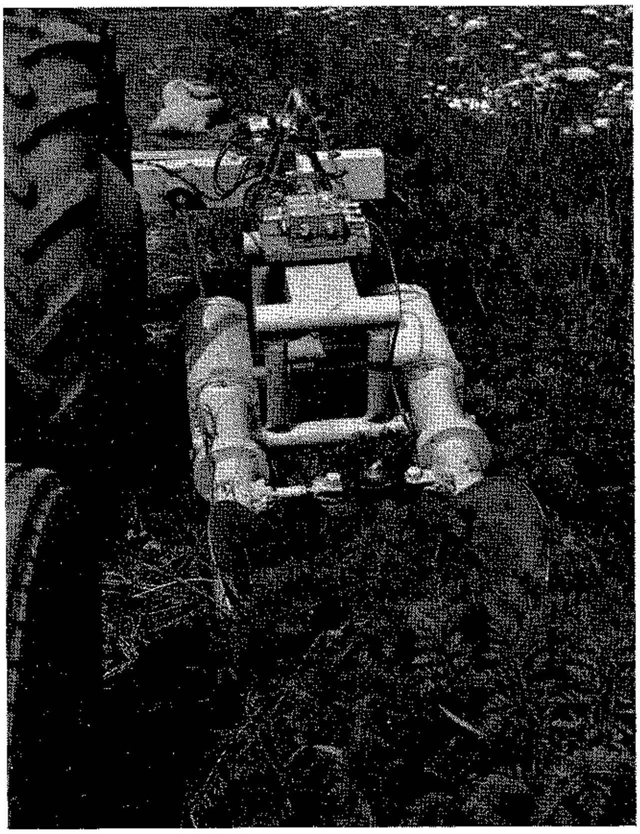


Fig. 2—Equipment for measuring forces

used for loosening deep-rooted crops like carrots, long red beet or leeks and a test rig was made to discover whether driven discs could also be used with an included angle of 60° which is more suitable for such crops. First trials showed that the discs had to be forced into the ground, but that the share they formed when the axes were tilted forwards loosened carrots satisfactorily, lifted them in a wedge of soil and had negligible draft. The sharp edge of new discs quickly eroded to a radius, but the share continued to function satisfactorily and disc wear was not noticeably high. Cutting deep notches in the discs appeared to reduce the wedging action between them, but was not practicable because feathery carrot tops became entangled in the discs and interfered with lifting the crop.

Later trials using a modified share assembly from an experimental harvester (figure 2) gave further information about the power requirements and forces acting on driven double disc shares, but did not give any insight into their mode of action although simultaneous recordings were made of the draught, the torque required to drive the discs and also of the lateral force tending to part them.[2]

Throughout the trials the share was maintained at constant depth and constant forward speed. The variables were pitch (angle of forward incline of the axes of the discs) and the ratio between forward speed and disc peripheral speed. No conclusion could be reached about the effect of pitch angle because the reading of the forces that were measured displayed very wide scatter. Increasing the peripheral speed of the discs, however, did not change the torque required to drive them: the power requirement was a function of the disc speed. Speeding up the discs, which had been thought likely to reduce the draught directly did not do so and minimum draught was obtained when the forward/disc speed ratio was about 1:9; higher draughts were obtained at both lower and higher ratios. There was also a definite relationship between the draught and the parting force caused by the horizontal wedging action of the soil between the discs.

These results are, of course, open to question because the trial was confined to one soil condition and one forward speed and it is quite likely that the share does not behave in precisely the same way in other soils and at other speeds. The optimum forward/disc speed ratio however, is worthy of further investigation because its use could give most efficient use of power, minimum draught (least effect on steering) and minimum parting force which giving least soil compression could result in easiest root cleaning.

In the final version of the harvester where the driven double disc share had to be easily adaptable for both digging and cutting, each disc was mounted on a separate arm extending forwards and pivoted from the main beam so that, although rigid in the vertical plane, it was free to swing horizontally thus varying the width of the share. The arms were lightweight rectangular hollow members with a telescoping section to allow the share to be extended forwards or retracted. A universally jointed shaft inside each arm transmitted the drive from a slipping clutch in the main beam to a light alloy worm gearbox on which the disc was mounted. In these worm boxes the thickness was kept to the minimum by positioning the thrust bearing of the worm shafts at the end of a 20 in. leg which was cast with the box. These legs were clamped inside the front end of the rectangular arms allowing the gearboxes to be rotated for any included disc angle. It was also simple to exchange the right and left hand gearboxes so that they could be positioned outside the discs for deep digging or above them for cutting and shallow digging.

The parting force acting on the discs was contained by a bottle screw positioned near the front of the rectangular members and a telescopic diagonal stay to the main beam allowed some lateral adjustment of the share assembly.

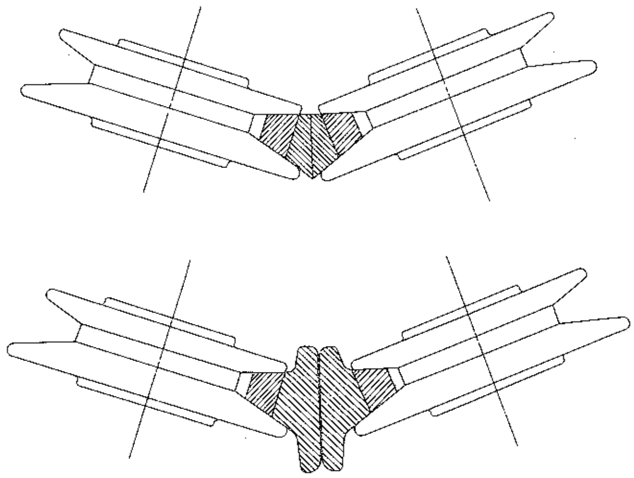
3. Lifting Belts

Trials with the N.I.A.E. Groundnut Harvester[3] showed that a wide variety of vegetable crops could be elevated if their tops were gripped between vee belts and from work with groundnuts the importance was known of matching the speed of the belts to the forward speed of the harvester so that individual plants were lifted vertically from the soil. Too high a belt speed caused the tops to be dragged backwards and too low a speed caused them to be carried forwards. In both bases the result was that some roots were left in the ground. In the universal vegetable harvester a very simple gearbox was therefore incorporated in the drive to the lifting belts to allow the machine to be worked in 1st, 2nd and 3rd gears.

When lifting belts were used in combination with a double disc share or cutter, it was also found that the point at which plants were gripped by the belts was important. Thus some crops had to be caught just as they were severed by the cutters, some gave best results when the tops were gripped at the leading edges of the disc share and others had to be gripped at the rear of the disc share where the roots had not only been thoroughly loosened but also had been raised a few inches by the soil wedging action of the discs. The provision that was made for extending and retracting the disc share made it simple to achieve the correct setting for each crop.

Accurate height adjustment of the pick up point of the belts was also necessary and although the use of depth wheels as in the groundnut harvester would have been satisfactory for roots, much more rapid adjustment was required for other crops. The lifting belt frame was therefore mounted on hinges on the main cross beam and raised and lowered relative to the share by a hydraulic cylinder. A stop capable of fine adjustment was used to prevent the belts from fouling on the digging discs and this stop combined with the hydraulic adjustment of digging depth gave the accuracy demanded for roots. In other crops the stop merely acted as a safety device and the driver made frequent adjustments of belt height.

The groundnut harvester and sugar beet harvesters employing lifting belts have all used D section vee belts ($1\frac{1}{4}$ in. wide) but although the front idler pulleys of these machines are much smaller in diameter than is recommended for power transmission, even smaller pulleys were necessary to enable the lifting belt assembly to be fitted between the digging discs when these were set with an included angle of 60°. C section belts ($\frac{7}{8}$ in. wide) and $4\frac{1}{2}$ in. diameter pulleys were therefore used and the axes of the pulleys were tilted together at the top: a modification which had three advantages. It reduced the overall width, made the pinch point between the belts the lowest part and also raised the pulley spindles so that they were clear of the soil even when the belts were working just above soil level. However, it was necessary to add soft rubber wedge-shaped sections to the belts so that tops would be gripped. The canvas wrapping around standard vee belts made it impossible to bond these wedge sections firmly to the belts, but two belt manufacturers provided special partially wrapped belts for the purpose. These wedge sections (figure 3a) were satisfactory for root crops where the tops were of no value but they marked Brussels sprouts and leeks. After trials when belts faced with $2\frac{1}{2}$ in. wide strips of 1 in. thick expanded rubber caused no damage to the crops a new wider wedge-shaped section of soft rubber (figure 3b) was bonded to the belts and was



Figs. 3a (above), 3b (below)—Soft rubber wedge sections bonded to lifting belts

satisfactory in all the crops in which the machine worked.

A considerable amount of care was exercised in the design of the lifting belt assembly to achieve adequate rigidity and lightness in weight without the sacrifice of adjustments necessary to enable the belts to grip thick Brussels sprout stems and wisp-like carrot tops. Heat treated aluminium alloys were therefore used for the arms supporting the pressure pulleys and even for the pulleys themselves, where hard anodising gave good wear resistance.

In field trials it was found that, although the pulley should be close together near the share where roots were likely to carry a considerable weight of soil, they could be more widely spaced after the first foot or so when almost all of the soil had fallen away. A wide range of spring loading was required to cater for all the crops and each pulley arm was therefore loaded by a tension spring with a screw adjustment.

Crop dividers were fitted to the front of the frame to guide bent Brussels sprout stalks into the belts and also to lift the tops of root crops so that all the leaves were gripped.

A simple hoop-shaped bar about three feet above ground level prevented bystanders from touching the discs accidentally and at the same time stopped loose clothing from being caught in the pinch between the belts.

4. Primary Elevator

Lifting belts, although suitable for many crops, could not be used for cabbages, lettuces or maincrop onions. With these crops the discs were set at an included angle of about 140° and it was therefore possible to use a 12 in. wide apron conveyor similar to that used in the potato digger for plant breeders already mentioned[1]. In an early version of the machine where the elevator was at a steep angle a lightweight slack conveyor belt above the elevator web and driven at the same speed prevented cabbages from rolling down to cause blockages behind the discs but it also prevented the driver from seeing the disc cutters clearly. In the final version, therefore, the slope of the primary conveyor was reduced and a standard hook link chain then conveyed onions satisfactorily. Cabbages and lettuces, however, tended to roll down even with the reduced slope and an elevator web was therefore used with pockets formed by using widely spaced cross bars. In the type adopted $\frac{5}{16}$ in. bars could be fitted at $1\frac{5}{16}$ in. centres or any multiple of this dimension.

When the slack belt conveyor above the elevator was discarded a simple reel was necessary to feed all of the crops from the discs onto the primary conveyor, but even when the paddles were faced with $\frac{1}{2}$ in. thick expanded rubber sheet, cabbages were marked when occasionally a paddle descended on the top of the head. Softer paddles would not convey any of the crops and after trials of a number of methods of spring loading, the paddles were made from a piece of thin flexible p.v.c. faced conveyor cloth folded into a U shape. A very lightly spring-loaded lazy tongs made from roller chain was fitted inside the U to give both tangential stiffness and the ability to collapse under a radial load that was required.

Very simple crop dividers were necessary to lift cabbage heads which were growing out of the row. These were made as flat-topped torpedos and incorporated guards for the cutting discs.

5. Crop Handling

At first only two methods of crop handling were envisaged. Bulky crops like Brussels sprouts and cabbages were to be fed into trailers and all others would be handled in box pallets carried on the machine. In field trials, however, it soon was found that small capacity box pallets were quite unsuitable for most of the crops. They were too large for lettuces, called for extensive modifications to allow leeks to be packed all one way and were filled so quickly with other crops that their use limited the rate of working.

It was therefore decided that lettuces and leeks would be packed by hand in 'bushel' boxes 21 in. long × 14 in. wide × $10\frac{1}{2}$ in. high; and all other crops would be elevated for transport in trailers or very large box pallets carried on a separate tractor. In addition, provision was necessary for bagging roots, partly because growers on whose land the machine was worked used washing plants capable only of receiving crop in sacks and partly also because there was some doubt about the advisability of bulk handling beetroot which are easily damaged and turnips which are only required in small quantities.

In every case, whether the crop was to be handled in bags, box pallets, bushel boxes or trailers, it was desirable that the handling unit should also convey the crop across the rear of the tractor to discharge it in a position where it would not interfere with the harvesting of subsequent rows. Thus two box pallets each 36 in. × 36 in × 28 in. high were carried on a frame across the rear of the machine and the outer one was filled by a 20 in. wide smooth surfaced cross conveyor from the primary elevator or the lifting belts. The conveyor cloth was cushioned on tension springs at the point of discharge of the elevator or belts to reduce damage to the crop and a short pivoting extension ensured that crop was lowered into the boxes. The boxes were discharged from the machine by a hydraulic cylinder which pushed the outer one beyond the tractor width before allowing it to tilt and slide to the ground. The same action pushed the second empty box into the loading position and when the hydraulic gear retracted another empty box could be placed on the frame.

The same cross conveyor was used when leeks and lettuces were handled in bushel boxes. Then the pivoting extension was replaced by a basket-shaped grid from which the crop was scooped by hand into the boxes. About 40 empty boxes were carried on a roller track magazine along the land side of the tractor and a second track on which the boxes were placed for filling also discharged full boxes.

The bulk handling elevator was 30 in. wide and, like the cross conveyor, conveyed the crops across the rear of the machine. Rubber covered flights at 15 in. spacings were necessary because the height of discharge necessitated an angle too steep for a smooth conveyor belt. The elevator was hinged in line with the land side tractor wheels so that the outer end could be lowered to reduce damage to crops when the trailer was only partially filled. Lowering this outer end to a vertical position gave minimum transport width.

For root crops a cleaning unit which is described in a later section took the place of the short conveyer. It was used in combination with a simple bagging attachment or with the bulk handling elevator.

Fig. 4—Harvesting carrots into bags

III. FIELD DEVELOPMENT

1. Root Crops

For all root crops 22 or 24 in. diameter digging discs were used. Best results were obtained in carrots when the discs were set at an included angle of 60° and the distance between them was either the minimum at which no roots were cut or that which allowed the lifting belts to be positioned sufficiently close to ground level to ensure that all the tops were gripped (figure 4). Other roots could be dug at a similar setting, but less soil was lifted with turnips and globe beetroot when the included angle was nearer 140°.

In most crops it did not appear to matter very much whether the tops were gripped before the roots were loosened by the discs or after, but when carrots were harvested in mid December most of the tops were dead and it was essential to move the share forward so that the belts gripped after the roots were loosened and raised an inch or two by the soil wedging effect of the discs.

The height above the crown at which tops were gripped was not sufficiently precise to allow them to be removed by a simple cutter mounted a fixed distance beneath the belts: the roots had to be accurately aligned to ensure that tops less than an inch long were left and that none of the roots was overtopped.

A variety of devices has been used in sugar beet harvesters employing lifting belts to adjust the height of the roots for topping. The simplest consists of a pair of polished steel bars about 2 ft long mounted under the belts with their leading edges close to them and their trailing edges about 6 in. below. The shoulders of the roots engage on the bars and the tops of those which have been gripped close to ground level are gently pulled down to a standard level for topping. When this device was tried in carrot crops, however, the bars had to be set so close together that blockages were frequent. Replacing the stationary bars with vee belts driven at the same speed as the lifting belts was more successful in single rows of carrots, particularly when fixed pressure pulleys on the belts were arranged alternately so that thick masses of top did not block between pulleys mounted opposite to each other. Notched discs on the same spindles as the rearmost vee pulleys cut the tops close to the crown and blockages occurred only when these jammed on small stones picked up by the lifting belts or on the stems of plants that had bolted.

In double rows, however, the standard of topping was low because the mass of tops was so great that individual tops could not be pulled down by the roots engaging on the levelling vee belts and blockages were frequent.

Even at 1 mile/h the machine had to top 80 carrots/second when working in double rows and after the failure of the vee belt topper it was believed that a device employing a system of mass topping would be more successful than one in which the roots were treated singly. A well-known topping mechanism, originally designed for dry bulb onions, deals with a mass of crop and consists of a bed of pairs of plain and spiral rolls driven so that each plain roll rotates in the opposite direction to its adjacent spiral one and is spring loaded against it. Out of season trials showed that a unit embodying this principle gave acceptable topping of carrots, white turnips and red beet with a tolerable amount of damage. When fitted on a harvester, however, its capacity in carrots was too low because feeding the tops into the pinch between the pairs of rolls required a high proportion of its area. Various devices to invert the carrots so that they landed tops first on the bed were unsuccessful, and the mechanism was discarded.

Its principle of working, however, was preserved and combined with that of the vee belt levelling device producing a topper which gave results as equally acceptable as hand work in carrots, white turnips and red beet and with the added advantages that it caused negligible damage to the roots, could not be blocked by overloading and discarded roots where the tops had gone to seed. Only large swedes with thick necks were not topped correctly (figure 5).

In this topper a pair of rollers, one with a $\frac{3}{16}$ in. high flute spirally wound on the surface and the other plain, are spring-loaded together and positioned below the lifting belts and in line with them. The front portions of the rollers are tapered, forming a vee into which all the tops pass freely and the rear portions are cylindrical. As in the vee belt levelling device the front is close to the belts and the rear portion is about 6 in. below them. The spiral roll is driven so that the linear speed of its scroll corresponds to that of the lifting belts and the plain roller is spring loaded against it. After leaving the tapered section, the tops are gripped firmly between the rollers and continue to be conveyed backwards by the scroll without check. At the same time the rotation of the rollers lifts the roots until the shoulders touch the rollers when the scroll shears through the top.

Besides topping, roots also required cleaning and it was important that the mechanism employed did not cause any damage. Shaking the roots as they were lifted by the belts gave good results, but was unacceptable because losses of carrots with weak tops were excessive. A roller brushing system was therefore adopted in which the rollers were covered with soft rubber studs. Besides cleaning the roots the spacing of the rolls on this cleaner could be adjusted to discard small worthless carrots. It

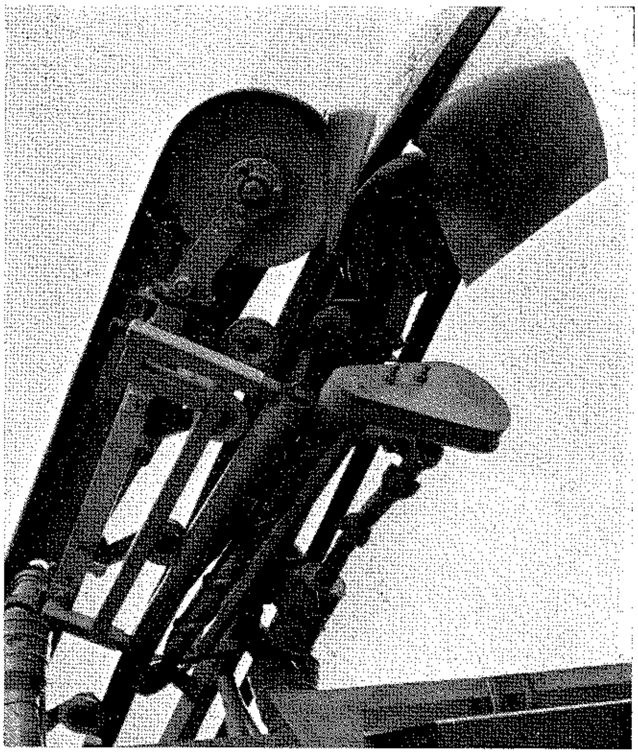


Fig. 5—Root topping attachment

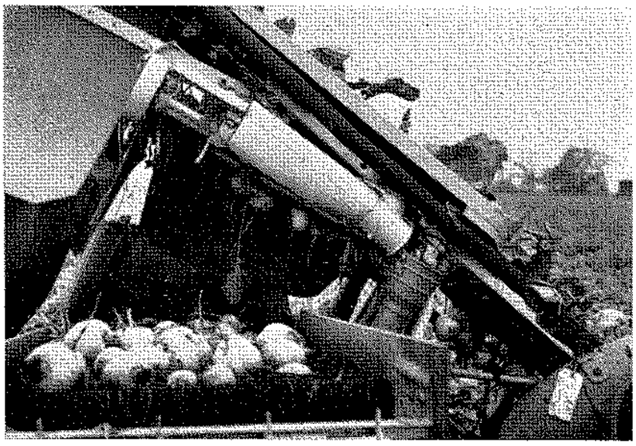


Fig. 6—Roller cleaner and conveyor

also carried the crop across the rear of the machine to a bagging platform or to a bulk handling elevator and provided an inspection table where an operator could be stationed to remove malformed and diseased roots (Figure 6.).

2. Leeks

The main problem to be overcome in mechanical leek harvesting is that a large amount of soil remains firmly attached to the fibrous root system even in light land conditions. Setting the digging discs of the harvester at an included angle of 60° and at their minimum width so that they cut through some of the roots reduced the weight of soil that had to be lifted by the belts but it was essential to grip the plants before they were fully loosened. Gripping them later was unsatisfactory because some fell over and were missed by the belts.

The cleaner which was adopted for carrots and other roots could not be used for leeks because it was important that no soil was allowed to get into the leaf axils where it would be difficult to remove. The most likely approach was to shake the roots while the leaves were gripped in the lifting belts. Flattened truncated cones driven by idler pulleys which were very successful in the groundnut harvester would not shake even sandy soil from the root system and a much more vigorous system was needed. A pair of bars mounted on links parallel to the belts and a few inches below them were crank driven to shake in phase with each other so that the roots received a sharp blow on each side for every foot of travel up the belts. This device was effective even in heavy land giving cleaning similar to that achieved by hand methods. Because the leeks were gripped by the flexible upper leaves, their only resistance to the vigorous action of the shaker was their own inertia. As a result damage was confined to the outer skin which is removed in the washing process before marketing.

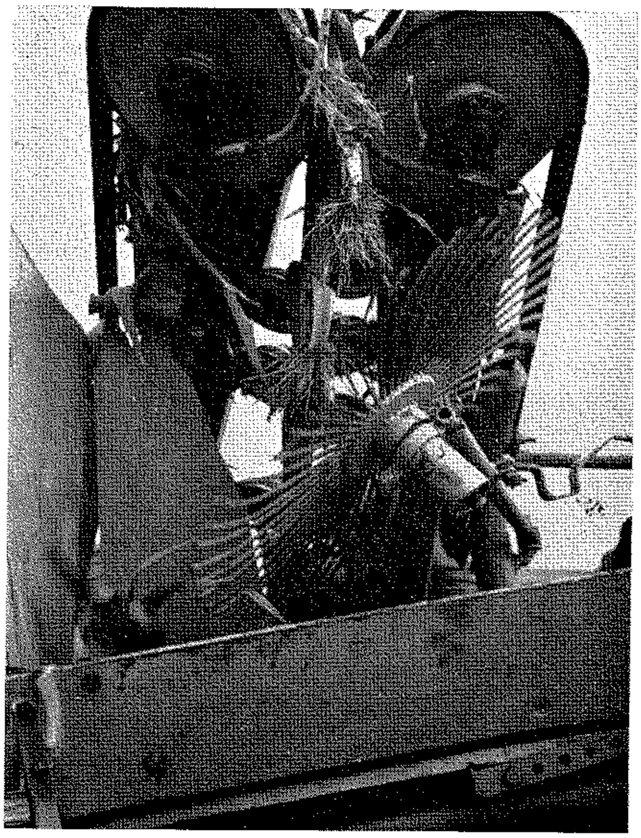


Fig. 7—'Orientating' wheel for leeks

Although the shaker cleaned the roots thoroughly it was still necessary to place the plants all one way on the cross conveyor to prevent contamination of the leaves by soil. An orientating wheel consisting of a freely rotating spider wheel set so that leeks dropping roots first from the lifting belts caused it to revolve, conveyed the roots forwards while the tops dropped vertically (figure 7). More than nine tenths of the crop was placed correctly and it was not always necessary even to have an operator to correct those which had been placed wrongly before they were packed into bushel boxes.

3. Brussels Sprouts

So that Brussels sprout stalks would be cut at ground level the right and left hand worm gearboxes on which the discs were mounted were exchanged so that the gearboxes were above the discs. Plain or even notch-edged discs, 16 in. diameter, spring loaded together against a stop so that they could disengage to allow stones to pass between them, would not cut through the stalks. The discs had to have saw-toothed edges to grip the stems firmly. Then their mode of action was similar to that of serrated edge kitchen scissors rather than that of circular saws. The teeth, therefore, required no set and sharpening was only necessary when they were too blunt to grip the stems. Accurate control of the height of cut was achieved by fitting shallow domes about 10 in. diameter on the undersides of the cutters. These followed the ground surface when the top link bracket on the main beam was unlocked and small alterations of the included angle of the cutters permitted fine adjustment of the cutting height.

At first it was proposed that an apron conveyor would be used to elevate the crop, but trials showed that some damage was caused to the crop and the front idlers of the conveyor working near ground level accumulated loose leaves which had previously been stripped off the plants by hand. Lifting belts, when soft rubber faces had been fitted, caused less damage and also did not lift any of the carpet of loose leaves which was disturbed by the cutters. Where the crop displayed extreme variations in height, or contained some badly twisted stems it was necessary to have someone walking behind the machine to glean the occasional stems which were not gripped by the belts, but in better conditions no plants were missed when the cutters were positioned so that they severed the stems just as the belts gripped them (figure 8).

The bulk handling elevator that elevated the crop from the lifting belts into trailers or large box pallets conveyed short stems crosswise, but was not wide enough for tall growing varieties which could be 3 ft 6 in. high. These

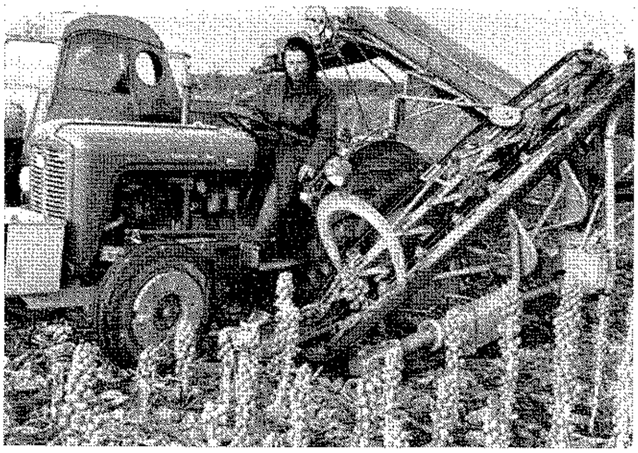


Fig. 8—Harvesting Brussels sprouts into large box pallets

Fig. 10—Harvesting lettuces into bushel boxes

were conveyed lengthwise and as a result the stems were jumble packed when 4 ft cube box pallets were used. Nevertheless machine filled boxes contained a weight of crop equal to that achieved by hand loading.

4. Cabbages and Lettuces

Cabbage stalks were cut by the cutters which were also used for Brussels sprouts but for minimum damage plain edged discs were used for lettuces. In both crops the height of cut was controlled by domes mounted under the cutters, but neither could be gripped between lifting belts. An apron conveyor was therefore substituted for the lifting belt assembly (figures 9 and 10).

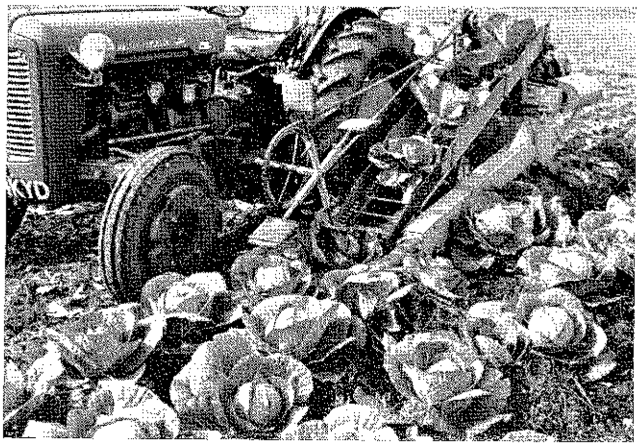


Fig. 9—Harvesting Fl hybrid cabbages

A few of the outer leaves of both crops were sometimes severed by the cutters but the quantity was insufficient to cause blockages at the front idlers and a leaf eliminator between the primary elevator and the cross conveyor removed most of them. The leaf eliminator consisted of a freely rotating roller placed about 3 in. beyond the end of the elevator and the same distance below its upper surface. Large objects such as lettuces or cabbages falling from the elevator, touched the roller and toppled onto the cross conveyor but loose leaves tended after touching the roller to be carried down, away from the cross conveyor by the return of the elevator.

Trials with small, 21 ft^3 box pallets showed that the output of the machine in cabbages was too great for any but a bulk handling method. With lettuces, however, bulk handling or even pallet boxes were considered likely to cause too much damage to the crop and, for lack of a faster method, the crop was packed by hand into bushel boxes which were discharged singly from the machine.

5. Onions

Only about three and a half thousand acres of maincrop onions are grown in Britain because home-grown

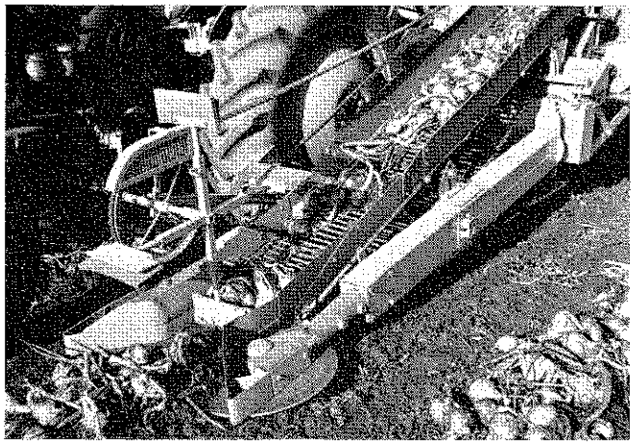


Fig. 11—Harvesting maincrop onions from windrows

sun-cured onions cannot be kept in store for more than a few months and do not have the pleasing appearance of imported ones. Experiments at the National Vegetable Research Station[4], however, have shown that artificial curing can give a product equal in appearance and keeping quality to imported onions. It has also been found that wilting the crop in windrows reduces the cost of curing without affecting quality.

A vegetable harvester with 12 in. diameter digging discs set horizontally was tried as a 2 row windrower, but did not produce a soil-free windrow because the discs were not independently mounted and had to work too deeply to ensure that no onions were cut. Crop windrowed by a commercial windrower, however, was harvested by the machine when 18 in. diameter discs set at an included angle of 140° and controlled by depth domes were used with an apron chain elevator. For first trials the crop was cross conveyed for handling in bushel boxes, but bulk handling is likely to be more suitable (figure 11).

6. Other Crops

Marrow stem kale, nursery root stocks, forest tree seedlings and gladioli corms have all been harvested successfully by the machine using attachments developed for other crops and growers and their advisors have suggested trials in spring greens, self blanching celery, parsnips, sage, hop setts and even blackcurrants. None of these crops is likely to call for specialized attachments although some might have to be grown in slightly abnormal row widths to suit mechanized harvesting.

Trials in summer cauliflowers on the other hand showed that it would be advantageous to reduce the bulk of waste material to be transported by stripping off some of the outer leaves before cutting the crop or during the harvesting process. This operation would require a specialized attachment to be designed for the machine. Other attachments could, no doubt, be designed for topping swedes, cleaning and bunching early carrots, threshing and cleaning groundnuts, topping and cleaning sugar beet or even for stripping potatoes of special varieties from their haulm.[5]

The machine, however cannot be used for harvesting all of the vegetable crops which lend themselves to destructive harvesting. Trench grown celery, for example, could not be harvested because it was so deeply rooted that 36 in. diameter discs would have been required and broad beans even when they were erect and in wide rows could not be gripped in the lifting belts without damaging the pods.

IV. RATE OF WORKING

Most of the development trials of the machine were of short duration, aimed at proving the efficacy of attachments in a range of crop conditions and output rates were not measured. One machine, however, worked for several weeks in Brussels sprouts with a daily output in 18 in. rows of between 4 acres a day when conditions were favourable and 2½ acres per day when the crop contained many lodged stems. In good conditions where the stems were upright and of even size output was limited because no provision had been made for driving the lifting belts at a speed corresponding to 4th gear in the tractor (4 or 5 mile/h) and the operator had to work in 3rd gear. In lodged crops the driver was unable to follow the rows accurately at high forward speeds.

It is probable that cabbages and cauliflowers can be harvested at about the same rate, but in root crops which are also handled in bulk the topping mechanism may limit the output. All the trials in carrots were made with sack handling which limited the rate of working to about 3 tons per hour, but from observations of short trials it appears likely that the topper will not be a limiting factor at at least twice that rate.

With leeks and lettuces the output was limited by the rate at which bushel boxes could be filled and handled. A tractor driver and two machine operators maintained a rate of about 3 boxes a minute in a leek crop, throughout the day. Their overall rate of working was of course reduced by stops to refill the magazine with empty boxes, but these three men, one of whom could have been replaced with better box handling equipment, harvested the same amount of crop as a gang of between 20 and 25 men doing the same task by traditional hand methods.

V. ACKNOWLEDGEMENTS

The development of the harvester was started at the N.I.A.E. in 1962 at the instigation of Mr W. H. Cashmore who was then Director. First trials showed that the lifting belt principle could be combined with driven double disc shares to form the basis of the design. During the early stages only a very small team was engaged on the project: but in 1963 it was decided with agreement of the National Research Development Corporation of Kingsgate House, 66-74 Victoria Street, London, S.W.1 that the programme could be accelerated by simultaneous development work on three experimental machines. The N.R.D.C. gave financial support towards the cost of construction of the machines and their patents department prepared the necessary patent specifications covering important design features.

Throughout 1964 and 1965 when the three units were under development all of the staff of the Cultivation Department's Development Section did some work on the project. That the programme was completed in so short a time was the result of their combined efforts.

Thanks are also due to members of the staff of the National Vegetable Research Station, the National Agricultural Advisory Service, N.A.A.S. Experimental Husbandry Farms and food processing companies, growers and others too numerous to mention individually for their very willing provision of crops for field trial, valuable advice and other services.

VI. SUMMARY

A vegetable harvester which was simple and also applicable to a wide range of crops was developed at the N.I.A.E. Adaptability was achieved by designing the machine as a tractor side mounted unit to which attachments could be fitted for groups of crops. For the sake of simplicity the machine employed the 'once-over principle' of working and its role in the harvesting process was confined to cutting or lifting the crop, delivering it in an undamaged, uncontaminated but in some cases only partially trimmed state into a vehicle or container for transport to a packing shed or factory where it would be prepared to meet the requirements of the fresh market or those for prepacking or processing.

A detailed account is given of the development of driven double disc shares which besides having negligible draft were also adaptable for several digging requirements and for cutting above ground crops. Most crops were lifted between vee belts faced with soft rubber, but an apron conveyor was required for other crops. Equipment was provided for bulk, sack, bushel box and box pallet handling and specialized attachments were developed for topping root crops and for cleaning leeks and placing them all one way on a conveyor.

Crops that were harvested successfully included carrots, white turnips, beetroot, leeks, Brussels sprouts, cabbages, lettuces, dry bulb onions, marrowstem kale, nursery root stocks, gladioli corms and forest tree seedlings. Further development work was required for summer and autumn cauliflowers and swedes but trials in trench grown celery were unsuccessful.

The rate of working in the various crops was not measured in field trials but indications of likely outputs were obtained.

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(*continued from page* 100)

small? Sometimes one might see as many as forty machines in one vining station, costing up to £250,000. Mr Coffey said that from his experience of other types of machinery, if one could double the dimension of the machine, one could generally obtain about four times the capacity at about twice the price. Did this apply to peas? Thirdly, there was a big problem in Ireland in connection with the harvesting of beans. There were seven different types of bean harvester in Ireland; two Dutch, two German, two English and one that they had made themselves. Of these machines only one of the German ones had any provision at all for dealing with stones. It was impossible to grow crops early in the season in Ireland because of the wet Springs and consequent difficulties with stones and dirt. Was any work being done on this problem? Another problem in Ireland related to the very small beanfields, for which most machines were far too large. In a short season, the working capacity of these harvesters might be only 50 acres per machine, giving a depreciation charge of around £8 per acre. This was by far the highest part of the harvesting cost. Was there any future for a much higher capacity machine and had any work been done on this?

Mr Gane said there were two schools of thought as to whether or not one should incorporate one's cutter with a loader or with a viner. It appeared, that the manufacturers felt that it was probably wise to keep these two operations separate. They could easily be combined but the point probably was that it would require perhaps only one stone to stop not only the cutting but the vining as well. There was an added safety margin in having the two operations separate. Mr Gane went on to say that there were, however, machines which would both cut and load; as he had mentioned in his paper, the pea pod harvester did in fact incorporate a cutter bar. There was no viner of which he was aware that had a cutter bar. All the viners relied on separate cutting and he thought that manufacturers probably regarded the mobile viner as being complicated enough without a cutter bar. It must be remembered that the vining season, particularly in a hot year, was a comparatively desperate campaign. Everybody was working absolutely flat out in cutting and vining, at a rate of probably 20-22 hours per day in many cases. One could afford to run no undue risk whatsoever because if a crop was delayed for even a day, it might be past the point of no return.

With regard to the size of the viner barrel, Mr Gane did not think that any work had been done at all on increasing the size for static viners but some of the newer mobile viners had certainly been provided with barrels of increased capacity. Concerning the separation of stones during pea pod harvesting, Mr Gane knew of no work going on in Britain, although the German machine was probably the only one with an adequate means of separation. He did not know of anybody else who had concerned themselves with that particular problem. As to the amount of room being taken up by bean harvesters, especially the towed versions, Mr Gane thought the answer would in the future be the same in Ireland as elsewhere, namely, that beans would be grown in 8 in. rows and would be harvested with a front mounted harvester which would take a complete swathe and which would be far more manoeuvrable than the towed machines in use at the moment. In other words the answer lay in the relationship between the present trend of plant populations and machines suitable for harvesting beans at those row widths and spacings.

In answer to a question about the disposal of sprout stalks and whether these had any value, Mr Hawkins replied that he did not think one need take stalks into the packhouse; this was a question that had been discussed at some length by a number of growers with whom NIAE had been working. The majority view had been that as sprout stripping machines need not be big cumbersome and difficult to handle; one might work them on the headland under a relatively simple shelter with one of the more modern sources of heat if necessary in the winter. The stems would then be left in the field. He was not able to state whether they were of any value as stock feed, but the consensus of opinion of the growers suggested that a suitable chopping mechanism could be employed after stripping to return the stems to the land. In answer to a further question about the cost of mechanical harvesting, Mr Hawkins replied that, until this year, the NIAE harvester had not been at a sufficiently advanced stage of development to provide reliable output figures for more than one or two crops. Whilst one could state the known output for Brussels sprouts, the rate of working in other crops had not been determined accurately. It was therefore impossible to arrive at accurate costs of harvesting. He felt moreover, that a research institute would be less likely than a manufacturer to estimate the capital cost of the machine accurately. NIAE had not, therefore looked too closely at the economics. Mr Boa however would be able to give some kind of comparison with hand work in terms of output per man and so on, where this was significant.

Dr R. O. Petersen (Massey-Ferguson, Toronto) asked whether anything was known about the need for timeliness of the harvesting of different types of vegetable in the UK and about the ratio between throughput and timeliness of the harvesting.

Mr Hawkins said that he had discussed this question at great length with the plant breeders and that it was agreed that the importance of timeliness depended on the characteristics of the plant. He had always hoped that the plant breeders would be able to combine even maturity and ability to hold in first-class marketable condition. Mr Hawkins cited an example of an amateur breeder of Brussels sprouts who claimed that after a certain date, provided the frost was not too severe, his variety continued to remain in prime condition for six weeks. Furthermore, in the course of that six weeks the plants shed all their leaves leaving bare stalks to harvest. This experience of an amateur breeder, coupled with statements from plant breeders who maintained that the necessary characters were present, suggested that even maturity and holding ability could make timeliness less important. Mr Hawkins added however that not all vegetables would remain in prime condition for long periods. These would have to be harvested when mature and stored until marketed. It was therefore necessary to add the cost of storage to the cost of preparation in the packhouse and at the moment there did not appear to be in this country, any reliable information about short term storage of fresh vegetables. Mr Devine would later on have a better suggestion to make and possibly Mr Gane also could comment as to whether the processors of peas and beans were in a stronger position than those concerned with fresh vegetables.

Mr Gane said that as far as peas were concerned, there were very considerable differences in the holding capacity of different varieties and it was one of the factors which his Organization had to take into account. If one was going to get a pack of consistent quality, it was extremely important not to be tied down to a particular day; it was a great help if one could say that tomorrow, or even the day after tomorrow, would do equally well. So far as dwarf beans were concerned, the position was very much happier in that their rate of deterioration was very much slower. As already mentioned, there was a problem at the moment of rapidly increasing yields during this period and one must be able to combine optimum yield with quality. Mr Gane said he was surprised that plant breeders were prepared to discuss the position at all because for centuries they had been working to provide plants which could be harvested over a very long period; one would start by taking a pea pod from the bottom, the next week you would have one from halfway up the stalk and the week after that you would have the top one. All of a sudden, the consumer says 'Now we want them all at once' and it was really asking rather a lot!

Mr M. J. Worth (Farmer) commented that Mr Hawkins had placed cohsiderable emphasis on the plant breeding programme and the effect that this would have on the complete vegetable harvester. Whilst he thought this was the correct long term view, Mr Worth said that from the short term point of view, he would like to know about different methods of selective harvesting with examples taken from crops which many farmers were now growing.

Mr Hawkins drew attention to the reference in his paper to lettuce where one could sense both the firmness and the size of the head; presumably these two properties could also be applied to cabbages in the context of selective harvesting. Assuming that peas and beans were taken care of by the methods already mentioned, what other crops needed to be considered? Drawing attention to Table I in his paper, Mr Hawkins maintained that everything down to leeks had been catered for, and with regard to asparagus he had drawn attention in his paper to the difficulty experienced by the Americans in finding a selective method of harvesting this crop. Mr Hawkins thought that for cauliflowers the combination of plant breeding and plant physiology work would arrive at techniques of growing cauliflowers that would give evenness in maturity and thus allow onceover harvesting to be carried out economically. Summarising, Mr Hawkins said that at the moment there was nothing which caused him to think that there was a case of any kind for the selective harvester in the UK. He could imagine that a selective harvester might show some advantage for a year or two in lettuce and cauliflowers, but this advantage would soon disappear.

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MARKET PREPARATION AND PACKHOUSE PLANNING FOR VEGETABLES

by E. S. DEVINE, MA, AMI AGR E*

Presented at the Annual Conference of the Institution in London on 12 May 1966

INTRODUCTION

On first examination market preparation presents a seemingly simple problem; general features like treatment, flow characteristics, storage, and any other special requirement within broad limits will be known. The origin and destination of a particular move or activity, distances and quantity of produce to be handled if not known can be estimated.

Although considerable information is usually available as to the requirements for any particular market preparation task the knowledge concerning its mechanization is scarce; this applies most strongly when comparing field operations with packhouse preparation.

Coupled with traditional hand methods of preparation is the increasing use of material handling methods; these can be introduced at all stages in the sequence of events which changes a growing vegetable into a market ready product. There is also present the need to reduce the multiple handling which hand conveying between field and market preparation necessitates.

Packhouse executives looking towards continuous flow or automation methods to give them efficiency in the intensified horticultural operations of today must not completely overlook the old batch system; this can still be efficient. The important concept is not whether the process is continuous or batch, but whether it is organized for an expedient flow of material through the packhouse. How the vegetables are handled is much more a function of the process than the method.

PROCEDURE

Recently the Machine Utilization Section of the National Institute of Agricultural Engineering began a series of investigations into both manual and mechanical methods of harvesting and preparing vegetables for market, and the collection of data for use either in planning mechanical and manual routines in the field, and the development of packhouse systems where more sophisticated marketing procedures are required.

Work study techniques are used to establish methodology and to collate time standards for planning. Methods examined are subjected to certain levels of systems study, a variation of method study applied to an overall system in which tests for efficiency are made on components of the system. The methods examined at each phase of the crop must ensure that the final product complies with the market standards laid down by the Ministry of Agriculture, see Table I.

Vegetable harvesting and preparation for market breaks down into three phases:

PHASE I
Field harvesting including all activities associated with the removal of the material from its growing point, marketing of unwashed produce, grading, inspection, trimming, packing and container identification, and the preliminary preparations such as outside leaf removal or root trimming before dispatch to the washing shed.

PHASE II
Packhouse preparation, that is trimming, washing routines, classification, quality grading, packing and labelling.

PHASE III
Prepacking operations, the supplying to prepack stations, the analysis of prepacking methods, market container filling and labelling, and container handling.

PHASE I

Vegetable Harvesting in the Field

Firstly, what factors affect the grower in his choice of harvesting methods.

(*i*) There is a limited season available for harvesting.

(*ii*) Selective or once over harvesting methods will depend on the evenness of maturity of the crop. The number of crops where 'once over' harvesting can be practised are limited to Brussels sprouts, onions and the root crops i.e. carrots, beetroots and celery, a future possible addition being summer cauliflower.

The next three most important factors are:

(*iii*) To use as little regular labour as possible.

(*iv*) To keep the direct cost of harvesting as low as possible.

(*v*) To minimise damage at all stages in the field harvesting programme.

The extent to which a grower can achieve any one of these latter factors will be affected by the availability and quality of both regular and casual labour.

Mechanical Harvesting

To date the use of full mechanization in vegetable harvesting in the U.K. is limited. Development work by

* Machine Utilization Section, National Institute of Agricultural Engineering

TABLE I

Market requirements for vegetables

Vegetable	Preparation	Style of Pack	Weight	Remarks
In Market Containers				
Brussels Sprouts	Graded, trim butts—quality inspected. Wash	Nets Boxes	20-28 lb	Avoid yellow leaves
Cabbage-Heads	Trim butt, must not extend more than ½ in below leaves. Grade	Bags Nets Bushel boxes	14-28 lb	Free from damage
Cauliflower	Grade for size and quality. Trim butts and leaves	Cauli-flower crates	By numbers	Avoid bruising
Celery	Trim butts, remove leaves with disease. Dirty or wash	Boxes Crates	By wt. or number	Avoid discolourations, and machine damage
In prepacks:				
Brussels Sprouts	Trim—grade—select for colour—wash	Nets, bags, lined cartons	8 oz to 16 oz	Small selected sprouts
Cabbage-Heads	Trim butts, remove discoloured leaves	Bags, direct wrap, plung pack	Individuals	
Cauliflower	Clean, white heads with trimmed butts, leaves cut level with curd	Bags, plung pack	Individuals	
Celery	Remove damaged leaves, trim to length. Wash	Bags, over-wrapped trays	Singly or in 2's or 3's	Avoid mechanical damage

the Cultivations Department of the N.I.A.E. on their Universal Vegetable Harvester has been described by Boa in an earlier paper.[1] This machine is still in the experimental stage and is being used by research staff in the field. Timed assessments to establish clear time standard for the work sequence will be made on commercial holdings using operators fully accustomed to their task. The once over harvesting techniques are essential with this type of machine harvester and to date the maturity pattern of such crops as lettuce, cabbage and cauliflower leave much to be desired. No doubt the plant breeders will endeavour to produce vegetable varieties having as their dominant characteristics evenness of maturity, now that mechanized harvesting seems the trend for the future. A further requirement from these vegetables is the ability to stand in the field from 7-10 days. This time is necessary if we are to make allowances for both machine performance and weather.

Manual Harvesting

Manual harvesting can be divided into:

(*a*) Selective harvesting—where the crop is inspected on a number of occasions and when each time a percentage of its plant population which has reached maturity is harvested, e.g. broccoli or cauliflower harvesting.

(*b*) Once over harvesting—where the entire crop is manually harvested in one operation. Factors affecting once over harvesting are the same as for mechanical harvesting.

By making careful time studies on manually performed routines it has been possible to highlight the points at which mechanization can be introduced. Now I propose to discuss one or two examples of each type of harvesting technique.

Broccoli and Cauliflower Harvesting

This crop occupies an average of 38,000 acres and represents 16% of the vegetable acreage of the U.K.

The two methods examined were both selective harvesting.

Method I

The crop was inspected by a team of four cutters each of whom walked a pair of rows at a time, they examined each head and then cut the ones considered ready, these were then thrown onto a trailer which was moving through the crop ahead of and in close proximity to the cutters. When a full load was cut the trailer was taken to the headland and tipped. Here inspection, trimming and packing was carried out. Alternatives to this are the use of bulk boxes and packhouse packing. The sequence of events was repeated until the entire crop was (*a*) inspected and (*b*) cut over and finished.

Method II

This method involved the use of a 'cauli-cart' built around a tractor, photograph No. 1, and had a basic routine

Photograph 1—(See text above)

similar to Method I. The inspection/cutting operators here cut and trim the heads and place them onto a net catching frame on the vehicle. The vehicle was also equipped with a platform on which grading and packing is done, provision is also made on the deck for the temporary holding of both empty and packed crates. This method of market preparation reduced the number of individual handlings by 50%. The build up of the work content for each method is illustrated in *Fig. I*, which shows in minutes the advantages of combining operations.

A comparison of methods indicates that the potential performance in broccoli harvested and packed is, for Method I 185 per hour and for Method II—294, this latter is an increase of 50%. In neither case is the effect of the availability of broccoli or cauliflower for harvesting shown. This has been removed to bring out the difference in methods, this may cause the work team to get out of balance on the 'cauli-cart' at either the cutting or the grading and packing points, thus causing an unnecessary loss of time. Team balancing will have to be carried out to match the volume of heads ready for harvesting especially when complete preparation is being attempted. The time spent walking between each actual cut is common to both methods and is a variable with each cut over, and can add between 5-15% to the total of the cutting operation.

In the broccoli crop i.e. 21,500 acres there may always be an uneven maturing, as here weather can affect the crop. Cauliflower varieties may be introduced that will mature all at once, to assist in mechanization and placement into storage for controlled marketing.

Brussels Sprouts

This crop respresents 46,800 acres or 19% of the total vegetable acreage. Two distinct harvesting techniques are

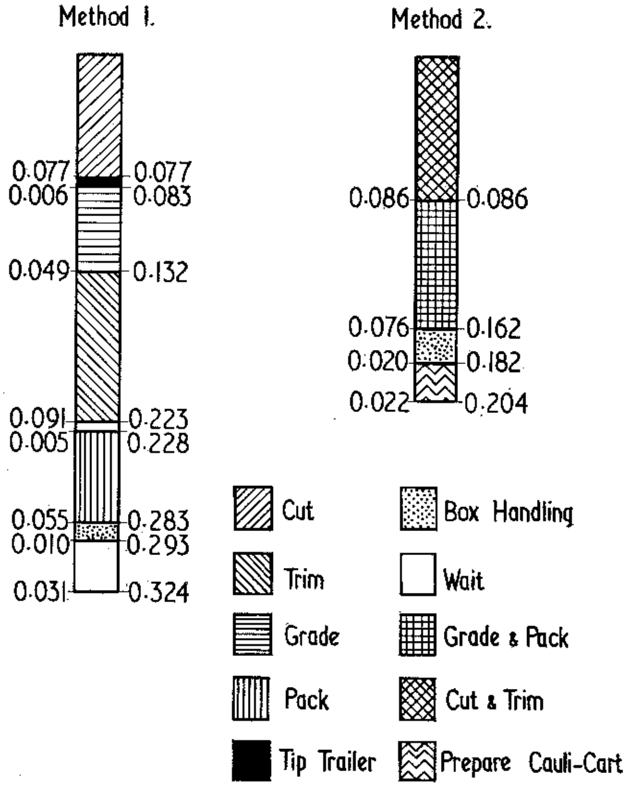

Fig. 1—Broccoli and Cauliflower harvesting

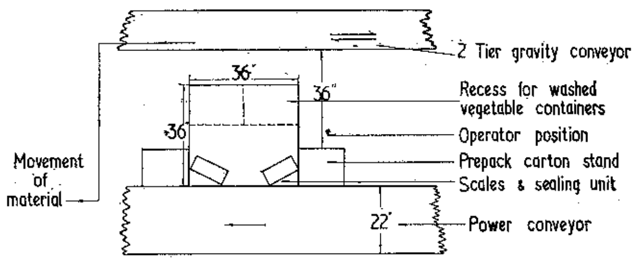

Fig. 2—Section of layout—plan view

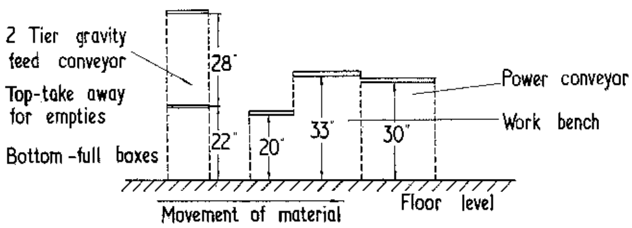

Fig. 3—Cross section showing working levels of layout

TABLE II

Brussels Sprout Harvesting—Manually into Nets
Quality Picking—Time in min/20 lb

Pick No.	*Prepare Net*	*Pick*	*Check wt*	*Tie*	*Carry out*	*No. of plant/net*	*Sprout No./Net*
1	0.39	5.71	0.20	0.28	1.09	18	288
2	0.39	4.61	0.20	0.28	0.82	24.6	311
3	0.39	4.95	0.20	0.28	0.81	22	295
Total Min	1.17	15.27	0.60	0.84	2.72		
% of time on each activity	5.68	74.13	2.91	4.08	13.20		

TABLE III

Brussels Sprout Harvesting—Manually into Sacks
Not Quality Picking—Time in min/28 lb

Pick No.	*Prepare Bag*	*Pick*	*Check wt*	*Tie*	*Carry Out*	*No. of plant/bag*	*Sprout No./Bag*
1	0.23	5.12	0.14	0.27	1.00	19	254
2	0.23	4.30	0.14	0.27	.80	20	201
3	0.23	5.42	0.14	0.27	0.77	25	297
4	0.23	9.31	0.14	0.27	0.80	40	522
Total Min	0.92	24.15	0.56	1.08	3.37		
% of time on each activity	3.06	80.29	1.86	3.59	11.20		

possible, (*a*) selective harvesting by hand and (*b*) once over harvesting by machine or by hand. Selective harvesting can be achieved in either of two ways (*i*) quality picking for direct marketing from the field or (*ii*) picking into sacks for quality assessment in the packhouse. Each method was analysed and time measured to provide time standards to use in comparisons with once over harvesting by hand, and subsequently by machine. Performances for each selective method is shown in Tables 2 and 3,[2] these are basic times and do not include allowances.

Additional allowances have to be added to the non-quality picking method to make up for the packhouse routines.

Once over picking of sprouts

This method means the complete removal of the sprout plant from the field. This technique involves the grower in three main operations in the field—(*i*) stopping the plants, (*ii*) deleafing and (*iii*) stem cutting, followed by stem transportation and finally removal of the sprout buttons from the stems. Table 4 shows the work content of this routine.[2]

TABLE IV

Once over—hand method, time in min/plant

Element description	*Time in min*
1. Stop plant by hand	0.040
2. Deleaf plant by hand	0.104
3. Hand cutting of stem	0.090
4. Transportation	0.006
5. Debuttoning	0.750
Total time=0.99	

On closer examination it is clear that this is a quick method of removal from the field but the major work content 75% is made up of debuttoning the main stem.

The areas of possible mechanization are at cutting the stem and at debuttoning. Check weights on stem to sprout ratios[3] removed from the field are shown in Table V.

TABLE V
Stem to sprout ratios

Variety	*Stem to spout ratio*
(*a*) No. 10	2.6 : 1
(*b*) Vremo inter	1.7 : 1
(*c*) 'In Bred'	1.6 : 1

This means that almost ⅔ of the transported material is waste. This is obviously unnecessary handling.

More detailed investigations into debuttoning by machine gives a reduction in time of from .75 min/plant to .067 min/plant. There is however a certain amount of stem tissue left on some buttons necessitating individual manual attention. This cleaning takes .05 min/sprout button, or expressed as a total time to debutton as .217 min/plant assuming 35% of the buttons need attention. This indicates a potential increase in productivity of 100% at the debuttoning operation. This results in an overall reduction of from 0.99 to 0.51 min/plant. Debuttoning times show that existing mechanization is transferring part of the labour from debuttoning to button trimming, both operations are on the quality inspection sector of the grading and packing line.

Conclusions on brussels sprout harvesting

Using the standard data available it is possible to make comparative analysis of the labour contents of each method. Table VI shows the time per lb for each method, and includes other activities where necessary to present the material in market packs in 20 lb nets.

Finally, Methods 1 and 2 remove much of the weather hazards out of Brussels sprout harvesting, against this their yield appears to be less than 50% of traditional crop husbandry methods. In Methods 3 and 4 the problem of labour is mostly overcome by piece work contracts. Of course this depends on the availability of labour for its successful operation.

Field layouts

Today in many vegetables as in sprouts, direct marketing following selective harvesting from the field can mean up to 33⅓% of the worker's day is spent on non-productive tasks, such as empty and full box handling from and to the headlands. Careful placement of roadways, optimum lengths of rows and correct material handling procedures will each help to reduce this loss of productive potential. In hand harvesting the optimum row length is 160 yd according to Rothenburger[4] of Germany, and then a cross path to facilitate produce handling. For machine work three factors affect the row length. They are, the capacity of the containers, the carrying power of the equipment and the characteristics of the vegetables. Where limited mechanization is used in 12 in. rows it is desirable to leave tractor pathways every 20 rows, this will also assist produce handling carried out by hand labour.

PHASES II AND III

Packhouse Operations and Prepackaging

Before going into either the marketing of washed vegetables or prepackaging the grower must give careful consideration to 'what is achieved' especially in terms of financial returns. Renoll[5] of Alabama rightly states that 'economic pressures on farm operations make it imperative that machinery needs and its utilization be accurately matched for efficient crop preparation and production', otherwise the economic consequences may be disastrous.

Today, packhouse development is something that is undertaken after careful consideration, in fact to achieve high performance at the correct unit costs two points appear on the average value curve, on the vertical scale the limit is capital, on the horizontal it is throughput. Today, the cost of going into packing and prepacking is hampering the potential of the smaller growers, without co-operation in the future it is possibly going to kill their very existence. In many vegetable crops as in other spheres of agriculture the harvesting cycle can be short, and in the future without adequate cold storage facilities

TABLE VI
Comparative labour contents in min/lb for each method of harvesting

Method	*Field Time*	*Packhouse Time*				*Total time*
		Hand de-buttoning	*Machine de-buttoning*	*Button Cleaning*	*Packing*	
1. Once over (hand)	.290	1.00 (.02)	—	—	.155	1.445
2. Once over (hand)	.290	—	.069	.150	.155	.664
3. Selective (quality pack)	1.338	—	—	—	—	1.338
4. Selective (non) (packhouse pack)	1.418	—	—	—	.155	1.573

Method 2 is 55.4% more productive than Method 1
Method 2 is 52.9% more productive than Method 3
Method 2 is 59.1% more productive than Method 4
Method 3 is 14.9% more productive than Method 4
When comparisons are made between Methods 3 and 4 the question of the economic breakpoint to cease picking becomes critical.

for controlled marketing it may not always be possible to get optimum machine utilization.

The efficiency within the packhouse depends very largely on the design and layout of the equipment within the building, which will be influenced by market considerations. In the past the failure to standardize market packs, failure to build packing sheds which are but production tools, and the long life of farm buildings in relation to technological changes have resulted in poor flow patterns, and the violation of all the laws of material handling.

In the simple packhouse suitable for changing vegetables from an 'as-harvested' to a washed, trimmed and graded product, both the vegetable characteristics and the estimated throughput determines the area required. The layout should be divided into three; reception where field containers are received and where the initial trimming is carried out, the washing, grading and packing area and the dispatch area. For the purpose of this paper the unit area of a B.S.I.[6] pallet 40×48 in. will be taken for the movement of bushel containers, bags or as the basal dimension of bulk bins.

The fixed equipment area requirement depends on the level of mechanization installed, which in turn depends on the volume of throughput and on the type of vegetables being prepared for market. Leeks and celery damage easily and are better handled in small containers. The reception and dispatch area remain constant at .07 ft^2 and .04 ft^2/bu respectively and then the area can be calculated from the projected throughput levels. Estimated floor space requirements for each area are shown in Table VII.

Prepack lines

Moving into prepackaging and consumer packs for direct sales means the handling of smaller units in both single and multiple form. Here it is advisable when planning to first appreciate the four basic principles of movement.

(*i*) The Principle of Minimum Movement—correct bench height, placement of materials, correct reach and vision paths.

(*ii*) The Principle of Balanced Movement—arms and hands should carry out a simultaneous and symmetrical movement—to reduce fatigue.

(*iii*) The Principle of Rhythmic Movement—to encourage speed.

(*iv*) The Principle of Natural Movement—which employs the easiest body movements.

In prepackaging the use of simple, moveable benches has much to recommend it, and offers the greatest degree of flexibility. The workers should follow an inward material flow pattern, see *Figs. 2 and 3.* It is important that the operator does not stretch beyond the recommended 27 in. reach zone otherwise time will be spent reaching and walking, this is unproductive work. The bench and conveyor levels should conform to the correct levels with working heights of 33 in. and all conveyors should be 2-3 in. higher or lower than the associated move. Where two tier conveyors are used the maximum height of the top conveyor is 50 in. giving a mid-box reach of 60 in. Failure to observe these simple measurements can result in production losses of up to 10%. When three or more packers are working alongside each other the take away conveyor should be live, gravity will only result in blockages and production loss.

Work going on at N.I.A.E. is aimed at producing time standards and output potential for operators in both the washing shed and in the prepacking area, an example of these standards for celery are given in Table VIII.

This gives a standard time of .229 min/head washed (times in brackets for one head), likewise the standard time for celery prepacking can be built up. The standard time for this task is .281 min/head, which means that a prepacked celery has a packhouse labour time twice that of washed and boxed celery. Before deciding to embark upon this sophisticated method of marketing it is considered necessary to carefully study the economics of the system and whether the supply of material to enable a long term marketing contract to be maintained is available.

FUTURE TRENDS

In conclusion it may benefit us to look at the factors most likely to affect the market preparation of vegetables. In the first instance it is likely that field layout and row spacing will have to be recalculated to suit mechanical harvesting routines for the once over crops, and to suit material handling routines for the selective harvested crops.

The high capital cost of going into packing and processing is likely to slow down development on all but the large production unit. To keep ahead of the obsolescence of machinery and the shortening of the packhouse mechanization cycle should be the aim of all producers, and should improve packhouse average value curves.

Turning to development it is considered that the trend

TABLE VII

Estimated floor space requirement

Daily throughput in bu	*Reception in ft^2*	*Washing area in ft^2*	*Dispatch in ft^2*	*Total specific area in ft^2/bu*
250	175	1200	110	5.94
500	330	2400	220	5.90
1000	660	2400	440	3.40
2000	1200	4000	880	3.04

TABLE VIII

Time standards for celery washing and packing—time in min/head

Element	*Basic time*	*R.A. %**	*Standard time*
Celery trimming:—			
1. Grasp head of celery from field crate, put it onto bench, trim top and bottom—put trimmed head aside	.132	15	.152
2. Put empty crate aside	.08	12.5	.090 (.005)
3. Reach for and grasp full crate	.136	20	.163 (.009)
To washer:			
4. Load celery onto washer, one in each hand	.06	15	.07 (.035)
Packing into crate of 42:			
5. Aside full crate	.086	15	.100 (.003)
6. Grasp empty crate	.072	12.5	.81 (.002)
7. Remove celery sticks from washer, one in each hand and place into crate	.04	15	.046 (.023)

* Relaxation allowance

will be towards the establishment of centralized all stage packing centres, which are supplied by a number of co-operating producers, each grower working to a cropping programme computed by a central production control, thus ensuring a better supply period with less risks of over production points during the year. The alternative may be the use of Grower Packhouses packing to a central marketing organization specification and complying with Ministry standards, also using a computed cropping programme. From these latter packhouses the top quality sample will be removed and sent to a central packhouse containing sophisticated and expensive prepack equipment, from whence all direct marketing to supermarkets will be made.

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Discussion to Papers by W. Boa and E. S. Devine

Mr W. Bolton (Co-Partnership Farms Ltd) asked Mr Boa to explain why the Universal Vegetable Harvester was developed for two man operation and not one man only.

Mr Boa replied that at first it had been intended to use box pallets with the machine and this would have allowed one-man operation. However, the decision to mount the machine on a small tractor that one would expect every vegetable producer to possess, meant that the tractor was not heavy enough to carry a bulk bin of any appreciable size. Consequently trailer transport was preferred. It might be argued that, as the machine had no draught, a trailer could be pulled behind it. The argument against that however, was that it was necessary to stop in order to change trailers. Mr Petersen asked firstly whether there was any particular reason for the crop engagement mechanism being on the left side of the tractor. Secondly, he asked about the application of this machine in nurseries, for pulling out young trees for re-planting or transplanting, gladioli, tulip bulbs and similar crops. Thirdly, Mr Petersen asked whether there had been any attempt to establish the capacity of the machine in terms of the total value of different crops in a staggered application that could be handled on one unit. Mr Petersen admitted that this question would be a difficult one to answer but it would be particularly helpful if some indication could be given of how many thousand pounds worth of crop this machine was capable of handling.

Mr Boa said that in answer to the first question, the left-handed mechanism had been developed to take account of the rule of the road in the UK where vehicles were driven on the left, thereby enabling the machine part, rather than the tractor part, to be driven over the grass verge in narrow roadways. Turning to the question of nursery crops, Mr Boa said that apart from gladioli, no work had been done with bulbs because most were harvested at a stage where there was no real connection between the part that was above the ground and the part that was below. Other nursery crops such as young trees, gooseberry bushes and the like, had been lifted satisfactorily but no attempt had been made to devise methods of handling them after lifting. Handling methods should not present any difficulties and he considered that it would be advantageous to harvest such crops, firstly because some were difficult to harvest by hand and secondly, because harvesting took place between November and February when it was difficult to persuade people to go out into the field. The same considerations applied to forest tree seedlings that were later planted out into the forest. In answer to the final question concerning the value of the crops harvested by one machine, Mr Boa gave an example of a machine that had been working in Brussels sprouts. Working at a rate between 2½ and 4 acres a day it had supplied one fifth of the intake of a processing plant.

Mr Coffey said that for several years past, he had been lifting carrots in Ireland with a belt-type machine of similar layout to the NIAE machine, but this was about the only resemblance. His machine had been in operation for a season of approximately 4 months, working all the time in fourth gear with a Fordson Major tractor and the output was about two-thirds of an acre per hour, which he thought was fairly high. Mr Coffey believed the cost of operating the machine was between £6 and £8 per acre and contractors who had worked these machines were able to make a profit. Mr Coffey said he was interested in the fact that Mr Boa had tried to keep his belt speed identical to ground speed so that a perfectly vertical lift was maintained all the time. He, on the other hand, had found when lifting leeks with his machine that if the belt speed was considerably higher than the forward speed of the tractor, he succeeded in ridding the leeks of a lot of dirt, due to the leeks being pulled apart in the belts and separating the tangled mass of roots; he asked whether Mr Boa had any experience of this and also whether any trouble had been experienced with the two power-driven discs when used in stony ground, such as was found in Ireland. Mr Coffey went on to question the need to make a multi-purpose machine and said that in Britain alone he felt there was a market for about 300 carrot harvesters at present, with replacements of about 50 machines per annum. Although this was not a large quantity, it was sufficient to interest the small manufacturer in producing a specialized carrot machine and he therefore did not think it was necessary to develop a complete multi-purpose machine. The carrot grower in general tended to grow fairly large acreages of specialized crops so that a multi-purpose machine had less application than a variety of special-purpose machines.

Replying to the point about belt speeds, Mr Boa said NIAE staff had found that if the belt speed was much higher than ground speed, leeks were damaged, as they were snatched from the ground. On the question of stony ground, Mr Boa said he could not recollect any case where the working of the driven disc share had been affected by stones. Mr Boa then turned his attention to the argument as to whether one had a specialized machine for any one vegetable crop or whether one had a universal machine capable of harvesting several crops. He believed that it was unrealistic to suggest a market for 300 machines in a carrot crop of 32,000 acres. Mr Boa said he also believed that if a farmer had a specialized machine, such as a carrot harvester, he might tend to continue growing carrots as long as the machine lasted although another crop might, in the meantime, have become more profitable. If, on the other hand, he had a universal type of machine, he could adapt his cropping programme very simply. This constituted an argument for the universal machine and another was that one could obviously envisage its use in connection with crops, such as leeks where the total acreage in the UK is 2,000 acres. If agricultural engineers concentrated on making only specialized machines, there could be no mechanization of such crops and the result could be that they might become so expensive that consumers would not be able to afford them.

Mr J. Love (J. Sainsbury Ltd) asked whether, in the advent of the new harvester, it would now be necessary for growers to change their views away from the bed system for root crops, to something like a 4 in. band sowing with rows approximately 10-12 in. apart. He also drew attention to the possible danger of damage to the crop resulting from the machine touching against adjacent rows. What kind of row spacing would be needed now for lettuce and how would one work with the plant populations advocated by Dr Bleasedale? Finally, Mr Love asked whether NIAE could not consult NIAB on the correct nomenclature for broccoli? He said it became confusing when one heard of such various terms as cauliflower, winter cauliflower, winter hardy cauliflower and broccoli.

Mr Devine replied that winter cauliflower had always been known as broccoli and the summer edition as cauliflower. Mr A. Brown said that some three years previously NIAB had decided that broccoli should be called winter cauliflower, but he had been interested to see in the trials this year that they were now being called spring cauliflower.

Answering the question about planting, Mr Boa said that mechanization obviously always had a cost; in the case of selective harvesting the cost took the form of special field arrangements, whilst in the case of onceover harvesting, it might be that one would lose something that was theoretically desirable such as the bed system. Mr Boa said he used the term 'theoretically desirable' because no one had yet devised methods of harvesting bed grown carrots without damaging a proportion of the crop. It was therefore reasonable to argue that the bed system should be modified to permit low damage systems of harvesting and in discussions between NIAE staff and Dr Bleasedale and his colleagues it had been agreed that although growing carrots in $2\frac{1}{2}$ in. squares was an ideal, it ceased to be so if one could not harvest them well mechanically. The same consideration applied to lettuces where the row width had to be increased from the theoretical optimum to perhaps 15-16 in. Turning to the question of damage caused by the machine, Mr Boa said that when the development programme was started, every effort was made to work with farmers and processors who judged damage against the standard of hand harvesting. This had been adopted by NIAE as the standard to be maintained.

MR E. J. CROWTHER (Ross Brothers Limited) said that he was one of the growers that had co-operated with NIAE and he went on to recount his experience of harvesting leeks with the universal vegetable harvester. Drawing attention to the reference in Mr Boa's paper to the output of the machine being equivalent to 20-25 men, Mr Crowther said that this was equivalent to an acre per day for a crop which probably had a gross value of not less than £250 per acre. He grew 12-14 acres of leeks and had spent all winter digging them up by hand; with a machine he could have got them up in a fortnight. He would prefer to grow a larger acreage but this machine would allow him to bring in the crop only when it was needed and when weather conditions were suitable, rather than struggling when the weather was bad. The crop could be stored either before it was washed, graded and packed, or afterwards. Mr Crowther said that his experience had been that the output of the machine easily exceeded the capacity in the packhouse. He could not claim any personal experience with the machine on the harvesting of sprouts but it appeared to him that the output of 4 acres per day was what processors and many fresh market producers required. This output was far more than he needed, but it would allow him to bring the crop in on one or two days in the week and market it over the whole week; alternatively, he could have a 'blitz' depending upon the state of the market. Mr Crowther said that one could continue trimming long after the harvesting machine had moved on to another job or on some other occasion: the stems with the sprouts on could be stored. He felt it was too early to become excited about harvesting lettuces by machine because the crop was not yet ready for handling by this means. The important thing from his point of view was to prove that the machine was capable of handling such a delicate crop.

MR F. J. BARKER (Farmer) said he wondered what steps had been taken to remove the soil from the crop before it was lifted without causing damage to the leeks. He enquired whether there was any method of high speed vibration, air blast, brushes or any other technique. The difficulty was that one could find oneself picking up more soil than crop.

Mr Boa replied that the shaking process had been found adequate for cleaning leeks grown in clay soils. Carrots, however tended to be grown in very light land and it was better to remove soil from them with a roller cleaner at the rear of the machine. Other root crops had been cleaned satisfactorily by the same attachment. Mr Crowther said that his experience with leeks had been that in heavy land, less damage had been caused by the machine than by hand labour because when they tried to shake a leek with a large lump of soil the leek broke in half, whereas machine shaking was sufficiently gentle and fast to break the soil into small pieces, which dropped off. Obviously, this might not happen in very wet conditions but with machine harvesting one could choose a better occasion to do the job. He had also noted that the machine did not damage the tops of leeks.

Mr Barker then commented that he harvested his leeks with a potato spinner which threw the dirt off quite well without breaking the tops.

Another speaker referred to the two ways of lifting with the universal vegetable harvester; one with an apron chain and one with a belt. He asked why lifting belts were necessary with Brussels sprouts when these presumably could fall onto the apron chain attachment which was used for cabbages.

Mr Boa replied that both methods had been tried and the belt was preferred because it resulted in less damage. Furthermore, because lifting belts were used for more crops it was preferable to use them also for Brussels. Mr Boa agreed that Brussels sprouts could be harvested with an apron chain but that it would result in some damage.

Mr Hawkins added that the use of belts rather than an apron conveyor was to be preferred because of trash left on the ground when the crop was deleafed. An apron conveyor picked up the trash, but belts plucked the stalks from the trash leaving the latter on the ground.

General Discussion to all Four Papers

MR BLAKE (Hunting Technical Services) asked about the use of this machine for groundnut harvesting. He asked whether they envisaged any problems regarding removal of nuts from the haulm and also whether the machine was likely to supersede the original prototype groundnut harvester, to which reference had been made earlier.

Mr Hawkins replied that basically the new machine had a better lifting mechanism than that which had been used on the ground nut harvester illustrated earlier. There was a risk of nuts being lost when a stationary blade was pushed underneath the row as a share and on some soils this loss could be as much as 25%. With the much gentler action of the double disc share on the vegetable harvester, much smaller losses could be expected. Thus, the machine could be used as a lifter or possibly also as a windrower to place bunch variety of plants all one way on the ground.

Mr Hawkins did not think the time was ripe for onceover groundnut harvesting, but if such a stage was reached, the stripping mechanism used on the groundnut harvester could almost certainly be fitted in place of the root topper on the vegetable harvester. Moreover, in place of the cross conveyor or cleaner for roots fitted at the back of the tractor, one might substitute the cleaning section of the groundnut harvester which was virtually a modified and enlarged combine harvester cleaning section. It should be a fairly easy step to combine the two machines and have a complete groundnut harvester based on the same principle.

MR B. MIZEN (F. & G. Mizen) referred to a period of at least 10 weeks in the county of Surrey during the previous year when it had been impossible to use any machinery on the ground at all and a large acreage of leeks had to be dug by hand. He asked how the universal vegetable harvester worked under very wet conditions and whether the height of the cutters would vary according to the firmness of the ground. He also asked whether in the event of the universal harvester being adopted on a large scale employing the system of onceover operation, more research could not be put into the storage of vegetables. He said that although cauliflowers could be kept for three weeks at present, he believed that six weeks would be desirable. Thirdly, Mr Mizen asked whether any mechanical harvesting experiments had been conducted with runner beans as opposed to ground beans and, fourthly, he enquired about the residual effects of dinoseb on all beet crops.

Mr Boa said that in his view one of the great advantages of the double disc share was that no matter how wet the field was, the crop could be harvested provided that the tractor could be driven across it. There must come a point however, where, as Mr Crowther had mentioned, one would do much better to wait until the conditions were more favourable. This strengthened arguments for minimum damage because storage would then be more feasible than if one had damaged the crop by attempting to harvest it under adverse weather conditions. It also, however, strengthened the argument that more research on storage was urgently needed

Mr Gane said that the only work of which he was aware that had been carried out on this particular problem of damage, had been in the United States where there had been attempts to produce a hand-operated machine which would pick runner or stringless French beans. He did not know much about this particular machine but believed that it had not and would not make very much progress at present. Runner and climbing beans, with their high cost of production and the heavy labour content involved were becoming much less popular. Their place was being taken by the dwarf snap bean which could be mechanically harvested with comparative ease. It was true that the quality of a runner bean, especially from the point of view of flavour, was vastly superior to that of the dwarf French bean. At the moment there was a race on and it was debatable as to who would win; whether it would be the plant breeder who would be able to introduce the flavour of the runner bean into the dwarf bean, or the agricultural engineer who would find a way of harvesting climbing beans. Mr Gane said an added point of interest arose from the comments that had been made on the spacing of various crops, including peas and beans. With the spacing being used at the moment for supported runner and climbing beans, it was obvious that the plant population was far below the optimum. If runner or climbing beans could conceivably be grown with the optimum plant population for maximum yield and if one could then harvest them, this would amount to real progress. It would result in first class quality and enormous yields of runner and climbing beans; much thought was being given to this but it had not yet advanced very far. Commenting on dinoseb herbicides, Mr Gane said dinoseb amine and dinoseb in oil were in fact herbicides which were not produced at all as residual herbicides; it was merely incidental that there was some residual activity. This was really in the nature of a temporary bonus until such time as really good post-emergent herbicides became available. The residual activity was limited probably to a week or two after application but it was to be hoped that in due course good residual herbicides, in the true sense of the word, would be developed and also good post-emergent herbicides which could be used later in the season.

MR F. NOBLETT (Massey-Ferguson (UK) Ltd) said he believed a bean was currently on the market which had the flavour characteristic of the runner bean.

Mr Gane said he was not aware that this had been successfully achieved as yet. The runner bean flavour was certainly being introduced into new varieties but he knew of none which was yet in commercial production on a scale sufficient to be of interest to the processing industry.

MR L. REYNOLDS asked Mr Boa what degree of training would be required by mechanics to cope with the maintenance of the universal vegetable harvester. Would there be many right angle bends in the drive and would this be by means of hydraulic motors, vee-belt drives, chains, or some other method? He asked, secondly, whether it would be a simple matter to remove the machine from the tractor so that the latter could be used for other jobs on wet days, when one should not be in the field. This was especially important if one was a small market gardener with perhaps only two workers.

Mr Boa replied that he thought it likely that a production engineer would aim at simplicity rather than something complicated. There were no hydraulic drives on the machine at its present stage but this did not necessarily mean that the simplest way to do the job was by doing without them. Answering the second question about the changeover of the machine from one crop to another, or removing it from the tractor, Mr Boa said that this too was, to some extent, a question for the production engineer. It would be reasonable to expect that even in its most elaborate form, the machine could be dismounted from the tractor in around two hours, or, in a simpler form, in as little as one hour. One should be able to convert from one form of crop handling to another in 20 minutes in certain instances and $1\frac{1}{2}$ to 2 hours in others.

Mr I. B. Warboys (University of Wales) said that whilst potato harvesting was not intended to be provided for, he would like to ask Mr Hawkins and Mr Boa whether in the future some of these design features could not be adapted to deal with maincrop potatoes as well.

Mr Hawkins replied that, assuming one was thinking of conventional varieties of potatoes, grown in the normal way, he did not feel that there was anything in the design of the vegetable harvester that would result in the potato crop being handled as effectively as by current potato harvesters. The vegetable harvester was not designed to deal with anything like the 300-400 tons of soil that had to be handled when lifting an acre of potatoes; there was no area of separation surface that would allow one to remove this quantity of soil at an economic rate. It did not follow, however, that the general layout that had been adopted could not be used for a mounted potato harvester but it would certainly not have the sort of proportions and dimensions of the machine under discussion today.

Mr W. Hearle (Gloster Equipment) asked Mr Boa whether consideration had been given to this type of machine being self-propelled?

Mr Boa replied that the power required was not very high; the discs required 5-6 hp to drive, as also did the belts. If one allowed approximately a further 3 hp for auxiliaries, one could say that altogether about 14 hp was involved in driving the machine. One might then be tempted to think that the machine could be mounted on a two-wheel horticultural tractor but in fact the main consideration was not the power required but the out of balance weight of the machine. Tractors heavy enough for carrying such an out-of-balance load were of the order of 35 hp, even though one was only utilizing 14 hp of that capacity. Mr Boa said he would leave discussion about the philosophy of self-propelled machines to Mr Hawkins.

Mr Hawkins said that the task at NIAE had been to find mechanisms that would harvest vegetables. If such mechanisms could be mounted on a tractor, they could equally well be used in a self-propelled chassis. The machine was mounted on 3-point linkage, although it was not actually carried on it. As Mr Boa had said, if it was desired to strip every vestige of the harvester from the tractor, this might take one or two hours, but one could drop the harvester leaving some fittings in situ, in 10-15 mins. It could be argued that a machine designed to be mounted around a 30-40 hp tractor, would suit many more people than a self propelled one but it was possible that design engineers and manufacturers might have different views on this.

Mr Petersen praised the way in which the four papers at this conference had been linked to each other to provide a complete picture. He said it seemed to him that this amounted to a classical case for what in North America was called 'systems farming', employing the 'mass removal' technique to distinguish it from selective harvesting. The application of such a harvester as this to mass removal, was in his view, the modern way of doing things. It had of course to start with the plant breeder. Planting and cultivation techniques also played an important part in increasing efficiency. Transport, handling in the field and processing were important, as had been mentioned already but the point requiring particular emphasis was the need for precision planting and seed bed preparation of the kind that one could see, for instance, in California. Mr Petersen said that the more he saw of the many different harvesting machines sold throughout the world, the more he believed that there must be a departure from the complicated selective combine type to the simple mass-removal type of harvester and consequently, the more would have to be done in the field with regard to handling and processing.

Captain Griffith commented that in Europe the practice was much more widespread of growing crops on the type of land appropriate to a given crop, instead of trying to grow everything everywhere. Capt. Griffith recalled the experience of an earlier speaker who had mentioned the difficulty of stony ground and its effect on disc shares. His own reaction to this would be that one ought not to grow that type of crop on stony ground. In Germany, if one wanted to grow sugar beet, one farmed around Hanover, where one paid about £1,000 per acre for land which was suitable for growing sugar beet. Similarly, potato growing would be carried out in the sands around Bremen where one could decide upon the correct machines for working in sand which was easy to shake off. Capt. Griffith said that he had been involved for 30 years with the vegetable grower and he was finding that the practice of using many hand controlled machines was dying quickly. The trend towards larger-scale vegetable growing would continue in years to come so that large tractors would be necessary. He questioned the wisdom of concentrating on the small tractor and he criticised the idea of producing these new machines with a left-handed mechanism merely because it was the practice to drive on roads, in this country, on the left hand side. Capt. Griffith expressed the hope that if Britain joined the Common Market, the rule of the road would change to the right, so that similar machines could operate over the whole of Europe.

1966 EXAMINATION RESULTS

INSTITUTION EXAMINATION

Pass

	Training Centre
Addison, W.	Bishop Auckland and Durham Technical Colleges
Barton, J. M.	College of Aero. & Auto. Engineering
Belton, D. H.	Yorks (WR) Institute of Agriculture
Bullock M. J.	Rycotewood College
Foulger, S. R.	Lackham School of Agriculture
Goodhew, H. L.	Lackham School of Agriculture
Parker, A.	Bishop Auckland and Durham Technical Colleges
Saunders, K. J.	Private Study
Stephens, E. G.	Rycotewood College
Turnbull, I.	College of Aero. & Auto. Engineering
Webb, P. A.	Rycotewood College
Wilkinson, D. T.	Rycotewood College

NATIONAL DIPLOMA IN AGRICULTURAL ENGINEERING (*Old Scheme*)

Second Class Honours

	Training Centre
Harty, G. A. N.	Private Study
Punia Hari, S.	West of Scotland Agricultural College

Pass

Ballard, R. A.	West of Scotland Agricultural College
Burr, I. R.	West of Scotland Agricultural College
Cullen, J. A.	West of Scotland Agricultural College
Kitching, R. B.	West of Scotland Agricultural College
Shippen, J. M.	Private Study

NATIONAL DIPLOMA IN AGRICULTURAL ENGINEERING (*New Scheme*)

Agricultural Approach Passes

Essex Institute of Agriculture

	Subjects passed with Distinction	*Subjects passed with Credit*
Allen J. W.		EST
Bartlett, D. I.	FME, EST, FMM, FE	
Bebb, D. L.		FME, EST, FMM, FBM
Blackwell, J.	FMM	FME, FE
Bowden, C.	FME, EST	FMM
Colwill, J.	EST	FME
Cooper, D. A.		EST, FMM
Disney, R. E. L.	FMM, BS	EST
Ellam, D. F.		FME, EST
Graham, C. J.		EST
‡Hann, M. J.		FME, EST, FMM, FBM
Hibbott, R. M.		FME, EST, FMM, FE
‡Keightley, M. S.	FME, FMM	EST, FBM

(*continued on next page*)

1966 EXAMINATION RESULTS

(*continued from previous page*)

Martin, M. S.	FMM	
Notley, P. M.		FME, FMM, BS
Prout, K. J.	EST	FME, FMM, BS
Robertson, M. A.		FME, EST, FMM, FE
Shapland, A. H. T. F.		FME, FE
Shipman, J. G.	FMM	FME, EST, FBM
Smith, R. A.		EST
Waterson, R. J.		EST
Webb, B. T.	EST	FME, FMM, FE

West of Scotland Agricultural College

*Blaty, J. D.	EST, FE	FME, BS
*Climie, J. H.	FME, EST	FMM, FE, BS
*Howat, D.		FME, EST, FMM, FE, BS
*Miller, J. A. C.		FME, FE, BS
*Shepherd, H. M.		EST, FE, BS
*Wilson, P. M.		FME, EST

Engineering Approach Passes

Essex Institute of Agriculture

Cartland, M. C.		AEPAE
Frost, A. C.		
Grice, A. R.		MCAP, FMM, BS
Nairima, A. J.		
Sapsford, R. P.		
Thomas, E. P.		

West of Scotland Agricultural College

Bell, D. A.		AEPAE
Herbert, J.		FE
Ngei, O. O.		FMM
Quansah, S. S.		FMM
‡Rushton, P. O.	FMM, FE	AEPAE, MCAP
Shaw, J. C.		
Turnbull, I.		MCAP, FMM

‡ *Holding Shell-Mex & BP Bursary Award*

* *ND Agr E awarded with second optional subject as endorsement subject*

Key to Subject Abbreviations

Subject (*New Scheme ND Agr E*)	*Abbreviation*
The Application of Engineering Principles to Agricultural Equipment	AEPAE
Mechanization of Crop and Animal Production	MCAP
Farm Mechanization Equipment	FME
Engineering Science and Technology	EST
Farm Mechanization and Management	FMM
Field Engineering	FE
Farm Buildings and Mechanization	FBM
Business Studies	BS

ELECTIONS AND TRANSFERS

Approved by Council at its meeting on 27 July 1966

ADMISSIONS

Companion	... ...	Harvey, B. H.	Essex
Associate	... ...	Blackwell, P. R. D.	Somerset
		Blom, M.	Warwicks
		Burlingham, D. H.	Worcs
		Crawford, J.	Lancs
		Dee, J. C.	Glos
		Jarrom, J. W.	Leics
		Jefferies, T.	Ches
		Loads, N. G.	Suffolk
		McNaught, J. B.	Warwicks
		Malham, G. F. W.	Yorks
		Monck, J. M.	Wilts
		Moorhouse, J.	Yorks
		Pickles, C.	Yorks
		Snook, F. J.	Wilts
		Townsend, I. R.	Warwicks
	Overseas ...	Smith, P. R.	Rhodesia
Graduate	... ...	Cape, R.	Berks
Student	... ...	Amos, G. E.	Bedford
		Colwill, J.	Worcs
		Godwin, R. J.	Beds
		Henderson, A. C.	Beds
		Linger, B. A.	Beds
		Perks, D. J.	Staffs
		Quansah, S. S.	Ayr

TRANSFERS

Member	... ...	Weir, J.	Edinburgh
Associate Member	... ...	Baldwin, A. L.	Warwicks
		Barnett, E. B.	Northants
		Gedye, I. D.	Salop
		Scamell, S. C.	Wilts
		Wood, E.	Lanarks
Graduate	... ...	Kellaway, D. H.	Lincs
		Roche, C. J. E.	Northants

BRANCH HONORARY SECRETARIES

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County Education Offices
Stracey Road, Norwich, Norfolk

EAST MIDLANDS

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The Farm Institute
Caythorpe Court, Nr Grantham, Lincs

NORTHERN

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University of Newcastle
Newcastle-upon-Tyne 2

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Exeter, Devon

WESTERN

H. CATLING, ND AGR E, AM I AGR E
Engineering Dept
Royal Agric. College, Cirencester, Glos

WEST MIDLANDS

K. M. THOMAS, AMI AGR E
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Staffs

YORKSHIRE

T. H. E. HARRISON, BSC(AGRIC), MSC(AGRIC ENG), GR I AGR E
16 Wood Lane, Ashenhurst
Huddersfield, Yorks

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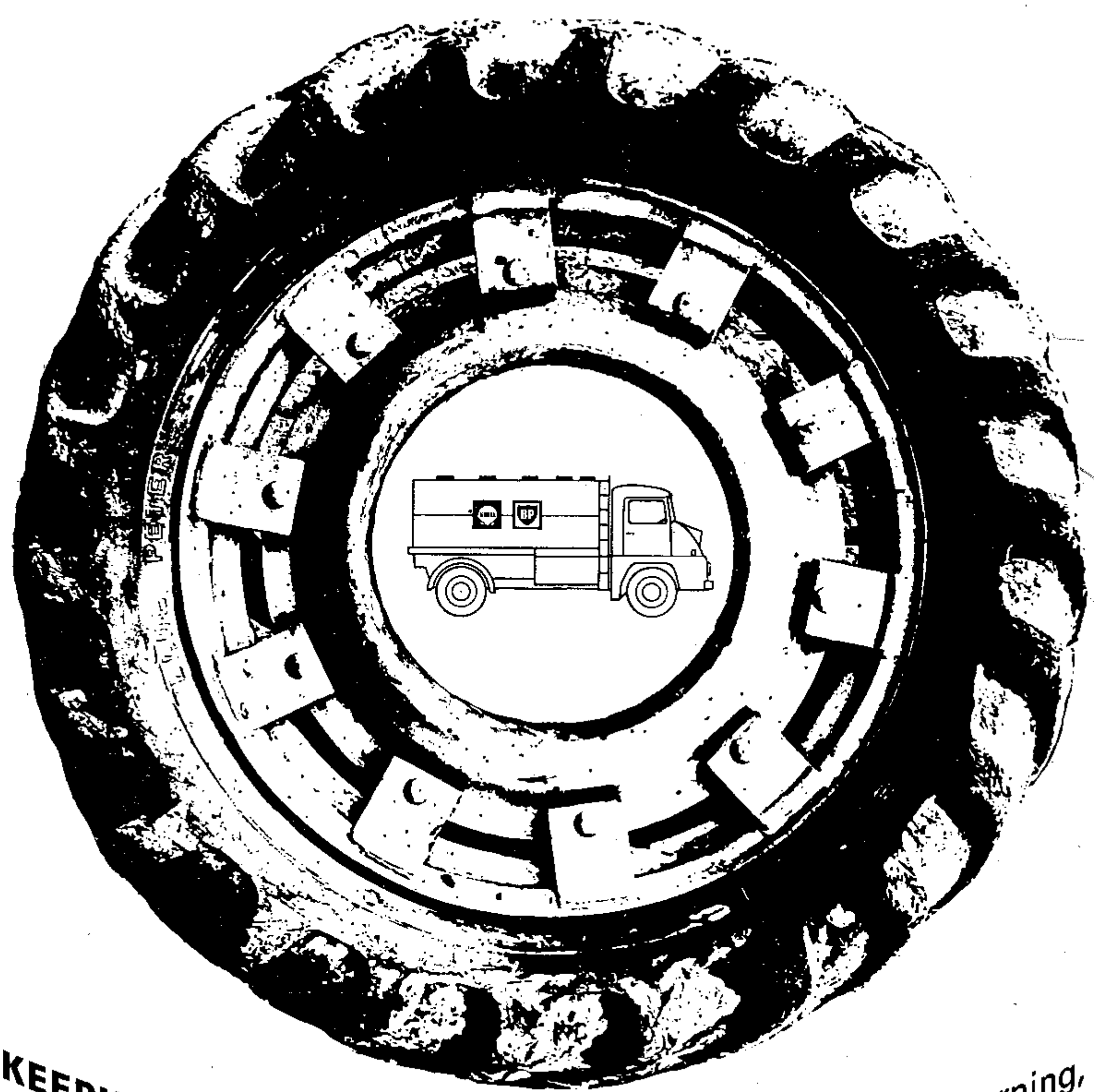
Abbreviations and Symbols used in the Journal

a	year
A or amp	ampere
ac	acre
a.c.	alternating current
atm	atmosphere
b.h.p.	brake horse-power
bu	bushel
Btu	British Thermal Unit
cal	calorie
c.g.	centre of gravity
C.G.S.	centimetre gramme second
cm	centimetre
c/s	cycles per second
cwt	hundredweight
d	day
dB	decibel
D.B.	drawbar
d.c.	direct current
°C, °F, °R	degree Celsius, Fahrenheit, Rankine
deg	degree (temperature interval)
dia	diameter
doz	dozen
e.m.f.	electromotive force
ft	foot
ft^2	square foot (similarly for centimetre etc.)
ft lb	foot-pound
G.	gauge
g	gramme
gal	gallon
gr	grain
h	hour
ha	hectare
Hg	mercury (pressure)
hp	horse-power
h	hour
in.	inch
in^2	square inch
i.d.	inside diameter
kWh	kilowatt hour

l	litre
lb	pound
lm	lumen
m	metre
max.	maximum (adjective)
m.c.	moisture content
m.e.p.	mean effective pressure
mile/h	miles per hour
mill.	million
min	minute
min.	minimum (adjective)
o.d.	outside diameter
o.h.v.	overhead valve
oz	ounce
Ω	ohm
pt	pint
p.t.o.	power take-off
qt	quart
r	röntgen
r.h.	relative humidity
rev	revolutions
s	second
s.v.	side valve
S.W.G.	standard wire gauge
t	ton
V	volt
v.m.d.	volume mean diameter
W	watt
W.G.	water gauge
wt	weight
yd	yard
$>$	greater than
$\ngtr$	not greater than
$<$	less than
$\nless$	not less than
$\propto$	proportional to
$\sim$	of the order of
° ′ ″	degree, minute, second (of angles)

The above abbreviations and symbols are based mainly on B.S. 1991 (Part 1), 1954



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