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THE INSTITUTION OF AGRICULTURAL ENGINEERS

SPRING OPEN MEETING

Second Meeting in the series under the general title:-

The Application of Agricultural Engineering in Developing Countries

PLANNING AND EXECUTING THE DEVELOPMENT OF AGRICULTURAL RESOURCES

27th MARCH 1969, at N.C.A.E., SILSOE, BEDFORD

The full programme for the day will be as follows:

10.00 Assemble — coffee

10.30 Introduction by the President of The Institution of Agricultural Engineers

10.40 Chairman of First Session — P. C. Chambers, Director, Land Resources Division of Directorate of Overseas Surveys — to paint a broad picture of the progress of techniques in land development planning — what can and cannot be expected of it, and the organizations involved.

11.00 **Paper I:**
Subject: Detailed paper on planning resource development
Title: Resource Development Planning with Special Reference to Integrated Feasibility Studies
Author: D. V. Chambers, Hunting Technical Services Ltd.

11.30 **Paper II:**
Subject: Detailed paper on physical techniques of interpretation of aerial photography and perhaps land classification
Title: To be provided
Author: R. G. B. Jones, Land Resources Division, Directorate of Overseas Surveys

12.00 **Questions** on the morning session

12.30-14.00 Demonstration of hard and soft ware used for the techniques described during the morning

13.00-14.00 **Buffet Luncheon**

14.00 Second Session Chairman — V. C. Robertson, Director & General Manager, Hunting Technical Services Ltd. — introduces session by highlighting the contrast of the problems between densely and sparsely populated territories

14.20 **Paper III:**
Subject: Case history of a Corporation development
Title: Some considerations based upon operating experience which affect the Agricultural Engineering aspects of the development of modern Sugar-cane enterprises
Author: R. F. Innes, Bookers Agricultural Holdings Ltd.

14.50 **Paper IV:**
Title: Introduction of Cash Crops to Peasant Farming and their Processing.
Author: R. Swynnerton, Agricultural Adviser, Commonwealth Development Corporation

15.20 **Open Forum**
To be opened by: Dr E. F. Schumacher, Chairman of Intermediate Technology Development Group and A. B. Behr, Manager of Special Projects, Massey-Ferguson (Export) Ltd.

16.30 Tea and dispersal
Demonstration remains open for those interested

TICKETS: Members (other than Student Members) 25/-; Student Members 15/-; Non-Members 30/-. The charges include advance copies of full texts or synopses of papers (depending on availability), morning coffee, luncheon and afternoon tea as well as admission to the morning and afternoon sessions of the meeting. *Early application for tickets is very strongly advised.*

INSTITUTION NOTES

Charting the Future

On 26 September 1968, the Institution held an Extraordinary General Meeting at which decisions of historic and far-reaching importance were taken.

The Memorandum of Association was amended to assist the Institution to become a Registered Charity under the Charities Act, 1960. As a result, application to be so registered has been granted by the Charity Commissioners from 1 January 1969. This status carries with it considerable taxation advantages and other financial relief, and will have a favourable bearing upon the Institution's role in the field of education, examinations and scholarship administration.

The Articles of Association of the Institution have been extensively amended. The main effect is that from 1 January 1969, two new grades of corporate membership come into being. These are Honorary Fellow and Fellow. The former grades of Honorary Member and Associate Member are discontinued. The existing grade of Member continues in force but with a much lower minimum age than before (25 instead of 40) and is to be directed at two types of engineer. First, the Member grade is regarded as the natural career grade for senior engineering technicians of diploma-level ability in agricultural engineering or mechanization. Secondly, the grade of Member is open to degree-level engineers and technologists who are below the minimum age for Fellowship (normally 35) and/or who have still to develop the necessary experience, responsibility and reputation to qualify as Fellows.

The non-corporate grades of Companion, Associate, Graduate and Student continue much as before. However, the spectrum of interests covered by the Associate grade has been widened so as to admit as many persons as possible who can benefit the Institution and themselves by this form of permanent membership. In line with the national policy of HM Privy Council, the use of designatory initials by Graduates and Students is withdrawn, but membership certificates will be available to these members on request, without charge.

Every member of the Institution was sent a notice in November entitled 'The New Membership Regulations and You'. Its purpose was to indicate the steps taken by the Council to ensure that the new regulations would not harmfully affect the status of anybody who was a member of the Institution before 1 January 1969. Simply put, Honorary Members and Members have been redesignated Honorary Fellows (HON FI AGR E) and Fellows (FI AGR E), respectively, and the title 'Honorary Member', with the designatory initials HON MI AGR E, is discontinued. Associate Members have become Members (MI AGR E) and the term 'Associate Member', together with the initials AMI AGR E, have been discontinued.

All other grades continue as before except for the withdrawal of designatory initials from Graduates and Students as explained earlier in these Notes.

Guide to Membership

From 1 January 1969, admission to any grade of membership or transfer from one grade to another, will be governed by the new standards which come into effect on that date.

A new Guide to Membership has been prepared in pocket-booklet form for the guidance of potential applicants and the industry generally. Every existing member is being supplied with a copy for his own use and further copies are available, free of charge, together with newly-designed application forms for admission or transfer, from the Institution Secretary or from local Branch Honorary Secretaries or Overseas Representatives.

The Membership Wallet

Making its first appearance in 1969, the Membership Wallet will, it is hoped, form an attractive and practical addition to the Institution's range of membership amenities. Much of the cost has been off-set by major administrative economies including the telescoping of a number of operations previously carried out separately; the Wallet thus conveniently contains not only a diary but also a membership card, subscription renewal notice, banker's order form, an order form for ties and other items, and some reply-paid recruitment postcards. Reaction to the idea has so far been most favourable and it is therefore hoped to extend and improve the Wallet in the light of experience.

Annual Subscriptions and Tax Relief

Coupled with a seasonal reminder that annual subscriptions become due on 1 January, it is worthwhile to mention once again in these columns that any member who pays his subscription out of income which is subject to UK Income Tax can claim tax relief on the amount of his subscription. With the new scale of annual subscriptions effective in 1969, this is an important consideration. As

Continued on next page

an example, a Fellow resident in the UK who pays tax at the standard rate, will find, after recovery of tax, that his annual subscription of £10 could work out at less than £6 nett. Proportionately similar tax benefits could apply to the other membership subscription rates, depending upon each member's individual circumstances. Every member who has not already done so is therefore advised to take advantage of this tax concession. All enquiries and negotiations should be conducted directly with the local HM Inspector of Taxes and not through the Institution.

The 30-Year Anniversary Endowment Fund

The plan, first announced in 1967, of establishing the Institution's capital reserves on a sound, long-term footing by means of the 30-year Anniversary Endowment Fund got properly under way in 1968. Progress can best be described as sure but slow. The Fund stands at well over £2,000 at the time of publishing this *Journal* and it is gratifying that, in the face of stringency in the national economy (not to mention the financial strains of the Christmas Season) donations continued to be received daily up to the end of 1968 from members throughout the world.

The Fund is still open and the Council hopes that *every* member will donate what he can afford. From January it will be possible to spread donations over a seven-year period by means of a Deed of Covenant. This will allow the Institution to benefit from the recovery of Income Tax paid by the donor, provided his donation has been contributed from income on which he has paid UK Income Tax at the standard rate. A leaflet is being supplied to all members, giving full details of this advantageous procedure, and including a special message from the President, Mr T. Sherwen.

Forthcoming Activities

Members are reminded that the Spring National Meeting of the Institution will be held at the National College of Agricultural Engineering, Silsoe, Bedford on 27 March 1969. The College Principal, Dr P. C. J. Payne, is the Programme Convenor and on page 166 of this *Journal* details are given of the whole-day programme entitled 'Planning and Executing the Development of Agricultural Resources'.

15 May 1969 is the Institution's big day of the year. The Annual Conference, Annual General Meeting and Annual Dinner will take place in London on that date; details be can found on page 172. Special attention is directed to the programme of the CIGR Congress at Baden-Baden to be held during the period 6-9 October 1969. An outline programme can be found on page 201 and early registration is vital.

The Institution's 1969-70 Session is well into the planning stage; this is likely to include whole-day events on such subjects as 'Ergonomics in Agriculture', 'Cultivations' and 'Design in the 1970's'. Details of these and of Branch Programmes for next season will be announced in the *Journal* during 1969.

Publications

As announced in previous issues, this Journal completes Volume 23, the four parts of which have been spread over two years. The Honorary Editor is glad to confirm the intention of reverting in 1969 to the normal quarterly cycle of publications, with issues appearing in April, July, October and January. The *Yearbook and Membership Directory* will appear in October.

Branch Notes

YORKSHIRE BRANCH

Report of Open Meeting held at the Yorkshire Institute of Agriculture, Askham Bryan, York, on Friday, 25th October, 1968.

The speaker at this meeting was Mr G. F. Angus of Direct Nitrogen Limited, who gave a Paper: Liquified Ammonia as a Fertilizer: Its Handling and Use.

Indicating that already some 4,000 acres were being treated with this fertilizer in Yorkshire, Mr Angus anticipated a doubling of this next year. In view of this expected expansion Mr Angus outlined the advantages of this fertilizer to the user before discussing the physical properties which themselves influenced the type of handling and application equipment.

Mr Angus described how this fertilizer is used in agriculture and illustrated solutions to some of the engineering problems involved, with reference to the appropriate British Standards. The difficulties of transfer between vehicles was outlined and the necessary safety precautions in terms of design and use were illustrated.

The equipment for injecting the material the necessary distance into the soil was described in detail with particular reference to the metering equipment. Mr Angus explained that the ammonia must remain as a liquid during metering and any gas present could cause large errors in the application rate.

Finally Mr Angus discussed the results which could be obtained. These can be better than with conventional fertilizers in terms of performance and cost. Wastage is reduced both in handling and in the soil, the nitrogen being released slowly while the plant is growing. Responses equivalent to those resulting from fertilizer placement could be obtained.

Report of Open Meeting at the Griffin Hotel, Leeds, on 22nd November 1968. A Paper 'External Applications of Tractor Hydraulics' was given by Mr A. W. Thomas, (Massey Ferguson Limited).

Using slides to illustrate his talk, Mr Thomas described different tractor hydraulic circuits and their components —making particular reference to the connection to, and control of external equipment, i.e. excluding the three point linkage. The layout of the controls and the associated internal design were discussed, including the different components and the applications and limitations. The varying, and often conflicting, requirements of different attachments were indicated, together with methods of overcoming these.

The use of multiple pumps to provide higher output when required was also covered, together with a description of the combining and other control valves peculiar to this equipment.

Mr Thomas also referred to the problems of coupling to a tractor, to obtain hydraulic power, the various systems at present in use, and the lack of any international standard. He suggested some improvements which he considered necessary to present systems before they could be proposed for international consideration. One further problem was the amount of oil needed to operate, in particular, high lift trailers, and the attendant risk of starving the transmission.

In conclusion Mr Thomas suggested possible lines of development including sequential operation for routine applications and the greater use of servomechanisms. Both these could lead to an increase in output from the tractor drivers by a reduction in the level of fatigue.

Following Mr Thomas' Paper, there followed a lengthy period of questions ranging over many related topics, and during which Mr Thomas expressed his opinion that pto shafts would be superseded by hydraulic drive even for high power applications, e.g. rotary cultivators.

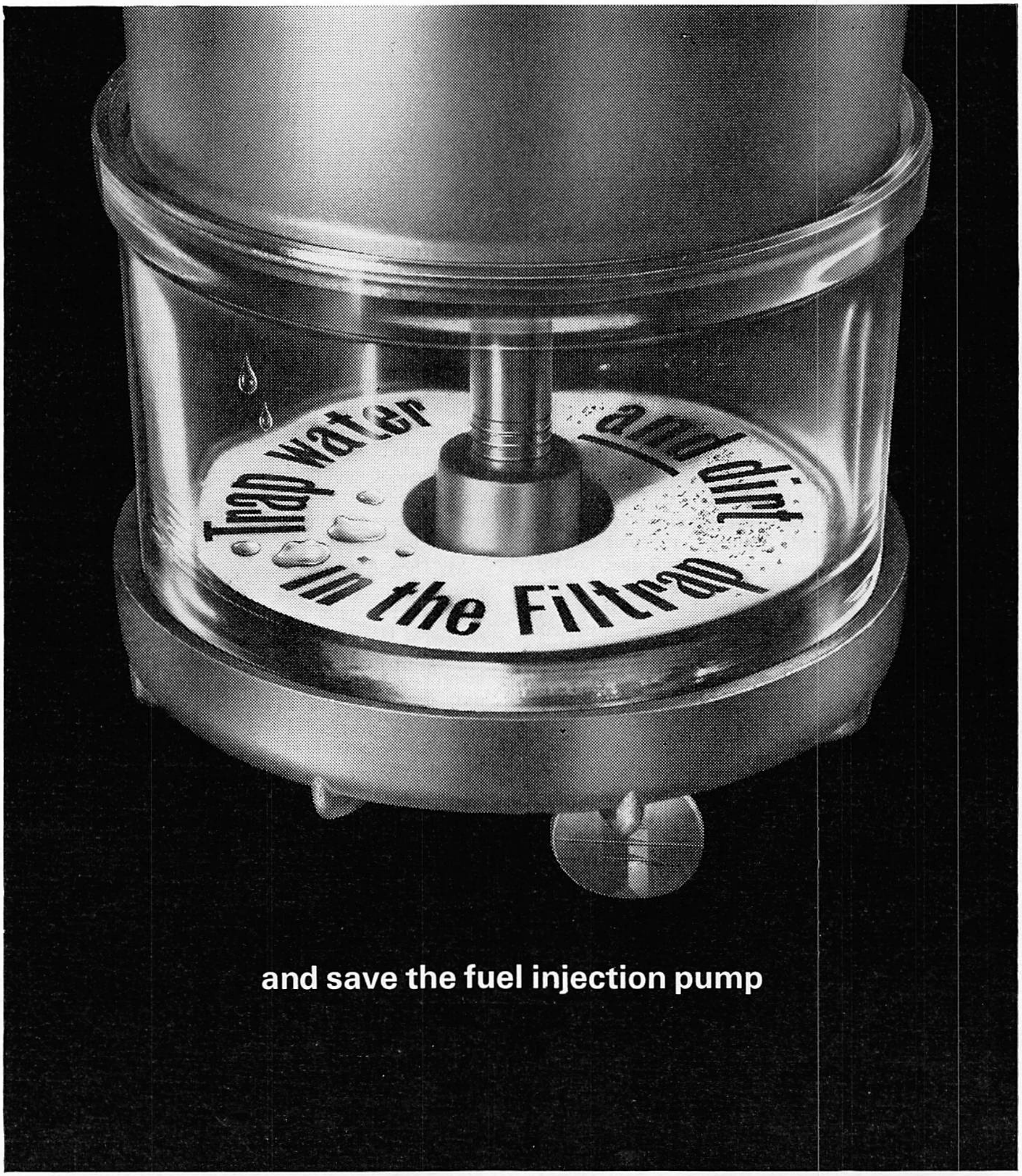
NORTHERN IRELAND GROUP

Almost 40 people including farmers, machinery dealers, advisors and engineers attended a meeting held in the Members Room at Balmoral on Thursday, 21st November.

The meeting was held with a view to setting up a Northern Ireland Branch of the Institution of Agricultural Engineers. It began with a talk by Mr R. A. Bayetto entitled 'Electricity in the Future of Agriculture'. Mr Bayetto has for many year been intimately concerned with the development of the use of electricity on the farm. In his talk, Mr Bayetto stressed the great pressures which a hungry world will place on agricultural production. With a world population increasing by a million a week, he foresaw that food production and distribution would become of international importance. To speed progress the Institution of Agricultural Engineers would, he envisaged, act as a clearing house for information which could improve the mechanization of world agriculture. The Institution would also continue in its role of promoting the training of suitable mechanics, technicians and graduate engineers.

Turning to the part electricity would play in farming the speaker emphasized that we are at the beginning of an era of increasing use of electricity on farms. The phase of mechanization is now giving way to automation with electronics replacing less reliable mechanical devices. Looking to the future, Mr Bayetto saw a vast expansion of the use of electrical and electronic equipment and the gradual spread of the use of electricity to powering field equipment. Following an interesting discussion on Mr Bayetto's talk, Mr J. K. Bennett, Secretary of the Institution of Agricultural Engineers, gave a résumé of the aims and functions of the Institution. He said that the meeting

Please turn to page 215



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NEWSDESK

World Conference on Agricultural Education

The Council of the Food and Agriculture Organization gave enthusiastic approval today to plans to hold the first World Conference on Agricultural Education and Training in Copenhagen, Denmark, in 1970.

Council delegates stressed the importance of having a 'grass-roots' type of conference that would be of practical help to developing countries in their efforts to improve their farmers' efficiency and living standards. Its role, according to one delegate, was to help make 'the peasant a well-rounded man' and a full participant in the life of his country. Another termed it a means of enlisting 'the peasant masses, who are the motive power of agricultural development'.

The conference, to be sponsored jointly by FAO, the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the International Labour Organization (ILO), was expected to take place for two weeks in July or August of 1970. The U.N. Secretary-General proposes to designate 1970 International Education Year, and the Copenhagen meeting would be a highlight of that year.

Holding of the conference is subject to obtaining the necessary financial support. The Government of Denmark, in addition to offering to serve as host to the meeting, has announced its readiness to contribute £50,000 towards its expenses. Negotiations are in progress with several governments to arrange for fellowships to facilitate attendance. UNESCO and ILO are expected to make substantial financial contributions. And an FAO contribution will be proposed for the 1970-71 budget, which will come up for approval at the 1969 FAO Conference session.

Two main topics have been proposed for the conference. One is the planning of agricultural education and training for agricultural development. The other is the development of a new strategy for investments of external aid to agricultural education and training in developing countris.

In addition, separate meetings were proposed on three subjects: higher agricultural education, intermediate agricultural education and training, and vocational training for farming and related occupations.

New Electricity Council Publication

The Electricity Council have produced a catalogue 'Electricity Information Service Agriculture and Horticulture 1968-1969' briefly describing the various publications, films, etc giving information on the use of electricity for Agriculture and Horticulture which are available through your Electricity Board. There are at present 22 booklets, 25 leaflets and 10 films. Also available is a series of filmstrips that can be used in conjunction with the appropriate publication.

Further information can be had from The Electricity Council, EDA Division, Trafalgar Buildings, 1 Charing Cross, London S.W.1.

Private Medical Care Through the BUPA Group

Illness always comes as a shock, possibly because we tend to think of it as something that only happens to other people—never to ourselves.

The often long delays in getting hospital and specialist care may also come as an unexpected surprise, particularly in cases of non-acute illness where finding oneself at the end of a hospital waiting list can mean waiting months, even years for a bed.

The only alternative to these frustrating delays is to be treated privately, a course many people never consider because they think it is beyond their means. In fact the advantages of private treatment can be secured quite cheaply—by investing in private health insurance.

BUPA or, to give it its full title, The British United Provident Association, is the largest organization of its kind in Great Britain. The Association is non-profit making; its aim being to assist its members to meet the cost of private medical treatment.

BUPA have announced the introduction of a Unit Scheme to replace the present Standard Scheme of benefits. The special group terms which BUPA offers members of the Institution of Agricultural Engineers still apply to the Unit Scheme. The advantages of a group membership are 10% rebate of normal subscriptions and immediate entitlement to benefit (the waiting period of three months is waived).

BUPA are also concerned with providing more and better accommodation for private patients through its associated organization, Nuffield Nursing Homes Trust's Homes.

The Trust, which is a registered charity, operates twelve modern surgical nursing homes throughout the country with a total of over 400 beds available. Last year nearly 11,000 people were treated in the Trust's homes.

Further details about our BUPA Group can be obtained from:

The Secretary
Group Management Limited
Prama House
267 Banbury Road
Summertown
Oxford

Apology

On page 149 in the Spring/Summer issue of the Journal, under the heading 'Discussions to the Spring Meeting of the Institution held in Milton, Cambridge in March 1968', the first question was attributed to Mr P. G. Baker-Beall, when in fact this question was posed by Mr J. G. Barker, of Western Machinery & Equipment Co., Ltd.

THE INSTITUTION OF AGRICULTURAL ENGINEERS

To be held at
The Institution of Mechanical Engineers
1 BIRDCAGE WALK LONDON SW1
THURSDAY 15TH MAY 1969

Annual Conference 1969

MECHANIZATION OF SPACED ROW CROPS

09.45 Assemble for Coffee
10.15 Annual General Meeting of the Institution (for members of I AGR E only)
10.45 Paper 1 **The Requirements of the Fresh Vegetable Market**
by Dr J. LOVE, Horticultural Adviser to J. Sainsbury Limited
11.10 Paper 2 **The Requirements of Vegetable Processing**
by V. D. ARTHEY, Agricultural Officer, The Fruit and Vegetable Preservation Research Association
11.35 Paper 3 **Growing Vegetable Crops for Mechanization**
by Dr J. K. A. BLEASDALE, Director of the National Vegetable Research Station
12.00 Discussion . . . of Papers 1, 2 & 3
12.30 Lunch Interval
14.15 Paper 4 **Crop Establishment**
by G. L. MAUGHAN, NDA, FI AGR E, National Institute of Agricultural Engineering
14.50 Paper 5 **Crop Harvesting and Handling**
by W. BOA, BSC (AGRIC), NDA, MI AGR E, National Institute of Agricultural Engineering
15.30 Discussion . . . of Morning and Afternoon Sessions
16.30 Tea and Dispersal

Annual Dinner

To be held at
St Ermin's Hotel
CAXTON STREET
LONDON SW1
THURSDAY 15TH MAY 1969

18.15 Reception
19.00 Dinner

The Guest Speaker will be:

Sir LEONARD DRUCQUER, C ENG
Chairman of The Council of Engineering Institutions

TICKETS

	Non-Members	*Members (other than Students)*	*Student Members*
Conference	60/-	50/-	30/-
Dinner	70/-	60/-	30/-

EARLY APPLICATION FOR TICKETS IS ADVISABLE

Applications should be accompanied by remittance payable to 'The Institution of Agricultural Engineers', and addressed to the Institution Secretary at Penn Place, Rickmansworth, Hertfordshire, WD3 1RE

THE USE OF HYDROCARBON OILS IN AGRICULTURAL SPRAYS

by

C. G. L. Furmidge, PHD, BSC, FRIC*

Presented at the Annual Conference of the Institution in London on 9 May 1968

INTRODUCTION

Hydrocarbon oils have played an important role in agricultural sprays for the past 200 years. The role has changed considerably during this period and it is likely to continue changing in the future. To appreciate the future role that hydrocarbon oils will play, it is necessary to consider the ways in which they are used at present and to examine the physical parameters of spray fluids that govern their performance under various types of application. Sprays are applied in many different ways and to simplify the discussion it is proposed broadly to classify sprays in three main types which are commonly referred to as *high volume*, *low volume* and *ultra-low volume* applications. It is impossible to put absolute values of spray volumes to these terms, but they may be defined as follows. High volume sprays are applied to saturate the target surface so that excess spray runs off; in crop spraying the volumes employed will depend on the total area of foliar canopy but generally vary between about 20 gal/acre and several hundred gal/acre. Low volume sprays are applied as discrete drops on the target surface and the drops should not coalesce to the point at which they will run off; volumes employed are usually in the region 2-20 gal/acre. Ultra-low volume sprays are used at a rate of less than 2 gal/acre and frequently as low as 2 pints/acre. Since the coverage of the target by spray fluid varies directly with the volume applied and inversely with the drop size of the spray[1], this classification also provides some guide to the optimum drop size. With high volume sprays the drop size is usually large, $\backsim$500μm; with the smaller volumes employed in low volume sprays, the size is reduced usually to between 200-400 μm; with ultra-low volume sprays, the drop size normally used is less than 100 μm.

In general, hydrocarbon oils are used in agricultural sprays in one of two ways:

1. as pesticides in their own right;
2. as solvents and carriers for synthetic pesticides.

HYDROCARBON OILS AS PESTICIDES

It is close on 200 years since the first recorded use of hydrocarbon oils as insecticides and up to about 25 years ago they formed a major proportion of the pest control products, both as insecticides and herbicides, then in use. They are commonly referred to as pesticidal spray oils and there are still very considerable quantities in use today (Eaton[2] quotes an estimated figure of 20-25 million gallons per year). However, their importance has decreased owing to the considerable advances made in synthetic pesticides over the last 25 years.

The development and use of hydrocarbon oils as insecticides, fungicides and herbicides has been fully reviewed by Fiero[3]. In the early days, insecticidal spray oils were frequently merely crude oil which was emulsified in water[4]. The variation between crudes made this a very chancy operation and a considerable amount of work was done on examining various grades of refined oil. Nowadays, it is recognized that oils with a fairly narrow distillation range are preferable[5] and the importance of molecular structure is now stressed although much more work could be done on structure-activity relationships of spray oils. Thus, it has been claimed[6] that certain aromatic fractions with a distillation range of 400-500°F, obtainable from certain types of crude, are highly efficient insecticides. On the other hand, paraffinic oils have been claimed to have better insecticidal activity than oils rich in naphthenes ([7 8 9]).

A most important advantage of insecticidal spray oils lies in the apparent inability of insects to build up resistance to the oils, the activity of which is reported as being due to the asphyxiating effect of a continuous oil film that envelopes each insect[10] and if this is the case, then it seems unlikely that resistance will build up in the future.

Phytotoxicity may be a problem with insecticidal or fungicidal sprays though its importance varies with the purpose for which the oil is to be used. For the 'winter washes' or 'dormant oils' applied to fruit trees in the winter months, phytotoxicity will be of little importance. With foliar spray oils, phytotoxicity is an important property but crop damage can be minimized by using oils with a low aromatic content and by applying the oils as emulsions in water rather than spraying the oils themselves.

For herbicidal spray oils, phytotoxicity is obviously the main requirement. A very wide range of hydrocarbon oils are phytotoxic; in general, light aromatic oils cause acute toxicity and heavy oils, such as fuel oils and diesel oils, cause chronic toxicity[3]. The mode of action of oils is considered to be due to deactivation of the plasma membranes of the cell owing to their solubility in the oil[11].

The major use of herbicidal oils is for total weed control for rights of way (power lines, railways, canals) and in orchards. For this purpose low-volatile oils with a high aromatic content (50-90%) are desirable[3]. The lighter, more volatile oils (distillation range 350-540°F) can be used for crops before emergence, after the crop seeds have been sown but before they have started to emerge[12].

Please turn to next page

*'Shell' Research Limited, Woodstock Agricultural Research Centre

THE USE OF HYDROCARBON OILS IN AGRICULTURAL SPRAYS—*from previous page*

Volatility is important here to ensure that the oil has substantially disappeared before the crop emerges. Some oils can be used as selective herbicides in post-emergence treatments to certain crops such as carrots[13], flax[14], beet and onions[3]. Great care has to be taken in the selection of the oil to avoid phytotoxicity to the crop and to avoid taint or off-flavour in the edible parts.

The chief disadvantage of pesticidal spray oils is that, weight-for-weight, they are much less biologically active than most of the synthetic pesticides presently used. To some extent this may be overcome by combining them with synthetic pesticides. Eaton[2] has described two products of this type, Bidrin-in-oil as an insecticide for scale and mite control on citrus and olives, and copper-in-oil for the control of Sigatoka disease on bananas and leaf spot on olives. Appropriate combinations of this type, when properly formulated, not only provide a spray that combines the biological activities of the synthetic pesticide and the spray oil but also can enhance the activity of one or both of the materials.

HYDROCARBON OILS AS SOLVENTS OR CARRIERS FOR SYNTHETIC PESTICIDES

The use of oils as solvents and carriers for synthetic pesticides has become most important during the last 25 years. Agricultural sprays incorporating oils can be broadly sub-divided into three main categories.

1. Solutions of the pesticide in oil; these are sprayed as oil solutions.
2. Emulsions, usually oil-in-water but now a range of water-in-oil emulsions is being developed also.
3. Suspensions of the solid toxicant in oil; these may be sprayed direct as oil sprays, or the suspension may be emulsified in water prior to spraying.

Oil Solutions

These have been widely used with insecticides such as dieldrin, DDT and BHC in control measures against the desert locust[15] and, to a lesser extent, in mosquito and tse-tse fly control. In the USA they have been used extensively against the spruce bud-worm and gypsy moth[16]. They have also been used as fogging concentrates for application in equipment such as the Todd Insecticidal Fog Applicator.

Usually they contain between 1 and 5% w/v of toxicant and so physically they appear similar to the pesticidal spray oils incorporating synthetic pesticides. However, since the oil in these formulations is used merely as a carrier liquid, its cost must be kept as low as possible and kerosene or diesel oil is frequently used. In sprays directed against flying insects such as locusts, the oil plays an important role in increasing insecticidal activity[17]. It must have a low volatility, so that the spray drops do not evaporate rapidly and the optimum size can be maintained for efficient impaction on the target insect[18]. (Both these points will be considered in more detail later.) Once impacted, the oil is considered to assist the penetration of the insecticide into the insect[19].

Oil solutions have not been used widely as general agricultural sprays for several reasons. Firstly, however cheap the oil used, it is still a more expensive carrier than water in most parts of the world. Secondly, the cheap oils are not good solvents for most pesticides; consequently, the formulations contain relatively low contents of toxicant and, unless they can be prepared at the place of application, transport costs are high. Thirdly, there is the danger of phytotoxicity due to the oil. All these difficulties can be overcome by the use of emulsions.

Oil-in-Water Emulsions

Early pesticide emulsions were usually the 'mayonnaise' type; a pre-formed emulsion containing approximately a 3:1 volume ratio of oil to water and which could be further diluted with water to provide a suitable concentration of pesticide for spraying. These formulations have diminished in importance over recent years and have been replaced by the 'self-emulsifiable oils' which will emulsify more or less spontaneously when added to water. Such oils contain the maximum concentration of toxicant that will remain in solution under the most adverse cold conditions likely to be encountered during storage (for most toxicants this will lie in the range 20-50% w/v) and some 4-8% w/v of emulsifiers.

The oils are selected on the basis of their solvent power and the aromatics, xylenes and trimethylbenzenes, are frequently used. Even so, many of the newer toxicants, including certain classes of organophosphorus insecticides, carbamate insecticides, triazine herbicides etc., are not sufficiently soluble in aromatic hydrocarbons to make economic formulations and alternative solvents such as the chlorinated hydrocarbons, ketones or alcohols may have to be used. In some cases the addition of small quantities of these last materials as 'co-solvents' may be used to increase the solubility of a toxicant in the aromatic solvents and also materials such as surface-active agents may be used as 'solubilisers' for toxicants.

The emulsifiers are normally blends of non-ionic and anionic surface-active agents containing at least three components. It is difficult to generalize on the emulsifier systems used since so many emulsifiers are available; every toxicant, and in fact every change in the constituent of a formulation, usually require a change in the emulsifier blend used. However, many formulations based on aromatic solvents can be emulsified by combining two non-ionic emulsifiers, one fairly hydrophobic and one hydrophilic, and an anionic material such as calcium dodecylbenzene sulphonate in varying proportions.

One of the major difficulties in formulating the self-emulsifiable oils is to ensure they will perform equally well regardless of the degree of hardness of the water used to dilute them. Formulations for general use are normally tested using water ranging in hardness from 0 up to at least 500 ppm calcium carbonate. The anionic-non-ionic type of blend described above will usually perform well in relatively hard water but good performance in soft water, particularly if it contains a considerable amount of organic matter, is often difficult to achieve and may require the addition of alternative types of emulsifiers.

Other materials may be added to oil-in-water emulsions to improve their performance. These include wetters to improve their wetting of foliage, humectants such as glycols to increase the rate of penetration of a systemic toxicant into the leaf, stickers such as viscous oils, resins and polymers to improve the persistence of the spray deposit to weathering and stabilizers to stabilize the spray deposit to chemical or photochemical degradation. Whether or not such materials should be used depends upon the type of application, the nature of the foliar surface and the physical, chemical and biochemical properties of the toxicant itself. It is impossible to generalize on the use of additives to sprays and the selection of the most appropriate materials can be made only by careful study of the interaction of a particular pesticide with the environment in which it is to be applied.

Water-in-Oil Emulsions

Recently, interest has developed in the application of water-in-oil emulsions as agricultural sprays since these may modify the size of the spray drops, the evaporation rate of the spray drops and the impaction and retention characteristics of the spray on foliage. The oil phase used is similar to that used in conventional oil-in-water emulsions, aromatic hydrocarbons being most usual. However, the selection of emulsifiers for these invert emulsions is much more critical than for oil-in-water emulsions. Because water forms the disperse phase of these emulsions, their viscosity increases as the ratio of water to oil increases but, as with almost all concentrated dispersions, their viscosity also varies with the shear to which they are subjected. This is illustrated in Fig. 1 which shows the variation of viscosity with sheer for three emulsions of different water to oil phase ratios. At a 10:1 ratio of water phase to oil phase, the viscosity at low shear is in excess of 1000 P; at very high shear, above the upper limit shown in Fig. 1, the viscosity reaches a limiting value (termed the viscosity at infinite shear) which in the case of the 10:1 water: oil ratio will be about 300 cP. Such high viscosities make it difficult to handle these emulsions in conventional spraying equipment and special equipment had to be developed[20]. In this equipment the oil and water phases were fed separately into a small mixing chamber that formed an integral part of the nozzle assembly. Thus, the viscous emulsion was formed within each nozzle and each nozzle on a boom had its own individual mixing chamber. More recently, the equipment has been simplified and consists of two tanks, one containing the aqueous phase and one containing the oil phase. The two phases are drawn separately to a common manifold that feeds a gear pump from which the emulsion is passed through a conventional boom and nozzle assembly. A coarse water-in-oil emulsion is initially formed where the phases mix in the manifold and the gear pump provides further emulsification as well as pumping the emulsions through the boom and nozzles.

This type of equipment places very stringent requirements on the emulsifiers used in the system.

1. The water-in-oil emulsion must form spontaneously upon simple mixing of the two phases in the manifold.
2. It must form at a very unfavourable phase ratio, that is with a very large excess of water to oil.
3. The emulsion formed must be stable enough to withstand the high shear encountered in the nozzles.
4. The emulsifiers must be present solely in the oil phase initially.

There appear to be relatively few emulsifier systems that are capable of satisfying these requirements. The selection of oil-soluble emulsifiers to satisfy these requirements has been discussed elsewhere[21] but the most important points can be summarized as follows:

A. The emulsifiers must be essentially non-ionic in character, the only exceptions being materials such as the fatty amine salts of long chain acids, where both anion and cation are adsorbed to the interface, so that no large net charge results.

B. The emulsifiers should adsorb rapidly at the interface.

C. The interfacial film formed must be of a relatively rigid type and it appears essential that some form of interfacial interaction, either electrostatic or through hydrogen bonding, between emulsifier molecules must occur if high water-to-oil ratios are required.

The addition of solids such as polyethylene to the oil soluble emulsifier blend can also assist in producing stable water-in-oil emulsions with high water-to-oil ratios[22].

Some of the emulsifiers used in the water-in-oil emulsions, long chain amines and amides particularly, may be phytotoxic and this can be a problem in formulating selective herbicides and insecticides. As with most types of cationic and anionic surface-active agents[23], the phytotoxicity of these emulsifiers decreases as the carbon chain length is increased from C_{12} to C_{18}, and this may be a further limitation that has to be placed on the selection of suitable materials to be used for any given application.

Suspensions in Oil

The difficulty of finding oils with sufficient solvent power for pesticides can be overcome by formulating solid suspensions of the pesticide in oil. For this type of formulation the lower the solubility of the pesticide in the oil the better and so it is possible to use paraffinic oils with very low vapour pressures. As will be discussed later, a low vapour pressure can be highly desirable when applying sprays at a low volume or ultra-low volume application rate. These formulations may possess further desirable properties in that they may increase the rate of penetration of some pesticides through leaf cuticles and may also improve the rain resistance of deposits.

However, it is difficult to produce formulations of this type that resist settling and caking of the dispersed pesticides during prolonged storage. This problem can be overcome by grinding the pesticide finely and increasing the viscosity of the oil but it would be difficult to handle and spray such a viscous product. A much more attractive way to overcome the problem is to build a 'false body' into the suspension by using oil soluble complexing agents to build up a rigid structure within the oil to support the pesticide particles. By careful choice of the materials used it is possible to prepare suspensions that are quite rigid

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under static conditions but that break down under very small shear stresses, thus allowing the formulation to pour and spray readily.

For ultra-low volume spraying, these concentrated suspensions can themselves be sprayed, although for other types of application they may be extended with more oil or emulsified to form either oil-in-water or water-in-oil emulsions prior to spraying.

THE PERFORMANCE OF SPRAYS

Having surveyed briefly the ways in which hydrocarbon oils have been or can be used in agricultural sprays, it is desirable now to look at the physical properties of sprays that govern their performance under varying conditions of application. Such an examination should help considerably in making predictions about the future trends in the use of hydrocarbon oils.

It is perhaps obvious to state that the performance of a spray application can be completely assessed only by examination of the biological result that the application achieves. However, the biological result is the end point of a very complex interaction of physical, physicochemical, chemical, biophysical and biochemical processes that start when the formulation is placed in the spray machine and end only when the biologically active principle is eliminated from the environment to which it is applied. In the time now available, it is impossible to consider all such interactions and for the purposes of the present discussion, it is proposed to consider only those processes that govern the formation of the spray and its impaction and retention on the target.

Formation of spray drops

Spray drops can be formed in a variety of ways; by purely hydraulic means, such as in fan-jet or cone nozzles; by compressed air, as in twin-fluid atomisers; or by rotary devices. In all cases, the size of the drops produced will be influenced by the physical properties of the spray fluid as well as by the construction and operation of the atomizer.

Consider the types of fan-jet nozzles that are commonly used for agricultural sprays. Two expressions may be used to describe the size of drops formed[24]. One expression relates the parameters responsible for the break-up of the central sheet of liquid and the second describes the break-up of the ligaments which tend to form at the edges of the spray sheet. For static, or slow moving nozzles, these expressions are:

for sheet break-up,

$$DV_E \propto \left(\frac{Q_s\gamma}{\rho_L}\right)^{\frac{1}{3}} \quad \left(\frac{\gamma}{r\theta\rho_L V_E^2}\right)^{\frac{1}{3}}$$

and for ligament break up,

$$\frac{D}{d} \propto \left(\frac{\eta}{\sqrt{d\gamma\rho_L}}\right)^{\frac{1}{6}}$$

where D is volume median diameter,

V_E is the velocity of emission of the spray through the nozzle,

$d = \left(\frac{2Q_L}{\pi V_E}\right)^{\frac{1}{2}}$ is the diameter of the ligaments,

Q_s is the volume of liquid emitted per second into the sheet,

Q_L is the volume of liquid emitted per second into the ligaments,

γ is the air liquid surface tension,

ρ_L is the density of the liquid,

r is the length of the liquid sheet from the nozzle to the point of break-up,

θ is the angle subtended by the leading edge of the sheet at the orifice, and

η is the viscosity of the spray liquid.

Hollow cone nozzles behave similarly though only one expression, that for sheet break-up, is required since ligaments are not formed[25].

The function $\left(\frac{\gamma}{r\theta\rho_L V_E^2}\right)^{\frac{1}{3}}$ can be related to Reynolds number (Re) for liquid flow through the nozzle orifice and is thus related to the viscosity of the spray fluid. This relationship is complex and takes the form shown in Fig. 2. This indicates that at high Re (low viscosity), the change in viscosity has little effect on drop size, at intermediate values of Re, drop size decreases with increasing viscosity and at low values of Re, drop size increases again with further increase in viscosity. The three ranges of Re shown in Fig. 2 appear to be common to all nozzles of a particular design, for example ceramic fan-jets with elliptical orifices. However, since Re is dependent on the dimensions of the nozzle orifice, the density of the fluid and its velocity in addition to its viscosity, it is not possible to place any viscosity limits on the three ranges of Re. The smaller the nozzle and the higher the operating pressure, then the smaller will be the viscosity differences in going from range 1—> range 2—> range 3. Taking an average sized nozzle, an Allman 9, operating at 30 psi to give an emission rate of approximately 60 ml/sec then range 1 covers viscosities up to about 10 cP; range 2, from 10 to 20 Cp; and range 3, from 20 up to about 300 cP, above which viscosity the nozzle ceases to function properly.

To compare the atomising performance of water-based and oil-based sprays on the basis of the above discussion, it is necessary to assume some average figures for the physical properties of the two sprays. A typical water-based spray (oil-in-water emulsion or dispersible powder) will have a surface tension of some 50 to 60 dynes/cm. This is slightly less than that of water because of the dispersing and wetting agents that will be present; it is the dynamic surface tension at the point of break-up of the liquid that is important, the equilibrium surface tension will be much lower than this value. The typical water-based spray will also have a density of around lg/ml and a viscosity of 1 cP. A typical oil-based spray will have a surface tension of about 35 dynes/cm, a density of around 0.9g/ml and a viscosity that may range from 1 cP to about 50 cP for the oil itself but can be as high as several hundred cP for a water-in-oil emulsion (because of the high shear rate in the nozzle orifice it is the viscosity value at infinite shear that is important in drop formation[26]). It is apparent from these figures that an oil-based spray (excluding highly dispersed systems such as water-in-oil emulsions) will almost always provide drops that are smaller than those of a water-based spray when the two fluids are compared in a given nozzle operating under identical conditions. With water-in-oil emulsions, the drop size may vary either above or below the value given by a water-based spray depending on the viscosity of the emulsion, but in general, the viscosity at infinite shear must be very high (for example over 100 cP in an Allman 9 nozzle) to produce drops that are significantly larger than those of an aqueous spray from a similar nozzle[27].

Evaporation of drops

The above discussion has been limited to the size of drops as formed by the nozzle; these will not necessarily be the same size when they reach the target. The rate of evaporation of drops is in itself a complicated process since it varies directly with the radius of the drop, which itself is progressively decreasing, and with the air-flow past the drop which varies as the radius decreases. The process is best examined on an analogue computer but, for the present argument it can be simplified by considering the evaporation of a very small drop, say 80 µm diameter. With such a drop, the evaporation proceeds as though the drop was stationary, due to the drop entraining a relatively thick layer of static air that moves with it.

Under isothermal conditions[28],

$$-\frac{dm}{dt} = 4\pi r D\left(C_o - C_\infty\right) \quad \ldots \text{(i)}$$

where m equals mass of drop,

- r is the radius of the drop at time t,
- D is the diffusion coefficient of the vapour in the air,
- C_∞ is the concentration of vapour in the atmosphere in the absence of the drop,
- C_O is the concentration of vapour at the surface of the drop (the saturation vapour concentration),
- $C_O = \dfrac{p_O M}{760 \times 22.4}$ g/litre where p_O is the saturation vapour pressure in mm of mercury and M is the molecular weight.

Consider drops composed of one of three liquids, water, a typical solvent such as xylene, and a heavy oil having the properties shown in Table 1.

If these drops were released from a height of 3.5 m in still air, they will take some 50-60 seconds to reach the ground provided the mass of the drop does not decrease by more than 10%. It is obvious that of the three liquids

TABLE 1

Some physical properties of three typical spray fluids

	Water *RH*50	*Water* *RH*90	*Xylene*	*Heavy Oil*
Vapour pressure mm Hg	13	13	5	1×10^{-2}
Diffusion coeff. cm²/sec.	0.22	0.22	0.077	0.04
Mol. wt.	18	18	106	400
C_O	1.38×10^{-5}	1.38×10^{-5}	6.23×10^{-6}	2.35×10^{-7}
C_∞	0.69×10^{-5}	1.22×10^{-5}	0	0

The time taken for each drop to lose 10% of its mass is given in Table 2.

TABLE 2

Evaporation rates of 80 µm *drops according to equation* (1)

	dm/dt (g/sec)	*Vol. initial, ml*	*Time to lose* 10% of initial *volume (sec)*
Water RH50	7.63×10^{-8}	2.67×10^{-7}	3.5×10^{-1}
RH90	1.77×10^{-8}	2.67×10^{-7}	1.5
Xylene	2.41×10^{-8}	2.67×10^{-7}	1.1
Heavy Oil	4.73×10^{-10}	2.67×10^{-7}	56.4

considered, only the heavy oil drops are likely to reach the ground or crop and the water and xylene drops will disappear long before they can impact.

A drop-size of 80 µm was chosen for this exercise since this order of drop-size is often considered the optimum for ultra-low volume spraying[29,30] and so only liquids having a very low vapour pressure will be suitable for this type of application. (Malathion, which is commonly used in ultra-low volume spraying, has a vapour pressure of 4×10^{-5} mm/Hg at 30°C.) Only the very heavy oils will meet this vapour pressure specification and the solvent powers of such oils for pesticides is poor. This is where suspensions of pesticides in oil rather than solutions of pesticides could become important in the future.

The high evaporation rate of xylene drops would suggest that water-in-oil emulsion drops based on xylene or similar solvents would also evaporate rapidly. In fact, the evaporation of water-in-oil emulsion drops can be very slow, provided the emulsion is stable. This is due to the very rigid interfacial film formed by the emulsifiers at the air/liquid interface as well as at the liquid/liquid interface already described. With a good emulsifier blend, the interfacial film is capable of reducing the vapour pressure of xylene by a factor of a hundredfold. However, in a drop containing a high proportion of disperse phase to continuous phase there is always a tendency for the disperse phase (water) to be expelled from the drop and form a water film around the drop surface. This produces a considerable increase in the evaporation rate. The expulsion of water is governed both by the stability of the emulsion, and thus is a function of the efficiency of the emulsifiers used, and by the ratio of disperse to continuous phase present in the emulsion.

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Spray drift

Spray drift can be most important since it represents a complete waste of spray material and in certain circumstances it can be hazardous. The tendency for a spray cloud to drift away from the target area will depend upon the drop size and the extent of the drift will be governed also by the distance of the spraying equipment from the target, the velocity with which the drops are projected towards the target and the meteorological conditions (wind and thermal currents) in which the spraying is carried out. Yeo[31] provides some values of the free-falling terminal velocity of drops of different diameters. A selection of these velocities is shown in Table 3.

TABLE 3

Terminal free-falling velocities of drops of unit density (31)

Drop diam. (μm)	*Terminal vel.* (*cm/sec*)
250	94
100	27
60	10.2
30	2.68
20	1.2

The effect of wind speed on drift under laminar conditions of air flow can be calculated by combining the terminal velocity and wind speed in a triangle of velocities[32]; Ripper[33] has tabulated drift against drop size for sprays produced by a number of types of machines. Under turbulent air conditions a simple expression of this type is no longer valid and prediction of drift is more difficult[34 35]. With aircraft spraying turbulence can be very serious in increasing drift and the recovery of drops of 200 μm and less under highly turbulent conditions may be only 40% of the recovery achieved under less turbulent conditions[14].

It is customary to quote the drop size of a spray in terms of its volume median diameter but it is necessary to know the spread of drop sizes around the median value, the drop spectrum, to be able to assess the liklihood of spray drift. From the relatively limited amount of information available, it would appear that changes in viscosity do not cause any great change in the drop spectrum[24], the whole spectrum is merely moved to lower or higher diameters depending on the operating conditions. A reduction of surface tension causes a decrease in the volume median diameter and at the same time it appears to extend the drop spectrum at the lower end[26], thus increasing the tendency of the spray to drift. Combining all the physical effects so far considered the following observations can be made regarding spray drift.

1. The drift of water-based sprays will be accentuated by their high evaporation rate but reduced by their relatively high surface tension.
2. The drift of oil-based sprays will be accentuated by their low surface tension but will be reduced if oils having a low vapour pressure or if water-in-oil emulsions are used.
3. In addition, the drift of water-in-oil emulsions may be either accentuated or reduced depending on the value of the Reynolds number for flow of the emulsion through the nozzle orifice. As shown in Fig. 2, the value of Re must be less than about 70 for fan-jet nozzles to produce a volume median diameter greater than would be achieved using an aqueous spray. Because the low surface tension of the water-in-oil emulsion will tend to increase the small drop spectrum, even lower values of Re (<50) should be employed when using water-in-oil emulsions to reduce spray drift.

Impaction and Retention

Once the spray drops have reached the target zone they must impact and be retained on the target. The impaction efficiency of drops supported in a moving air stream depends upon drop size, wind speed and the shape of the target. These aspects have been reviewed elsewhere[36 37] and it is not proposed to discuss them here except to point out that impaction efficiency decreases with decrease in drop size and with decrease in wind speed and increases with increase in the degree of curvature of the target, as shown in Fig. 3[37 38]. Thus, small spray drops carried in an air-stream will both penetrate through foliar canopies[39] and also tend to be collected on targets such as plant hairs and grass leaves better than large drops. However, as Fig. 3 shows, impaction efficiencies become very poor as the drop size is progressively reduced and it is undesirable to use drops smaller than around 50μm in most spray applications.

Drops may bounce on impact and this process is related to drop size and velocity, the surface tension and viscosity of the drop and the contact angle between the drop and the surface. Hartley and Brunskill[40] and Brunskill[41] have demonstrated the effect of surface tension and drop size on the bounce of drops from pea leaves and shown that there is a critical surface tension (for drops of about 250 μm is 45-50 dynes/cm) above which retention is very low and below which retention is very high. For any given spray fluid there is also a critical drop diameter below which retention is high and above which retention is low. The critical drop size increases as the surface tension falls and is about 100 μm in the case of water drops on pea leaves.

The tendency for drops to bounce will decrease with increase in viscosity as more of the impact energy is used up in overcoming viscous forces as the impacting drop progressively deforms. A further requirement for a drop to bounce is that it should have a high advancing contact angle on the surface and that there should be little hysteresis in the contact angle on that surface. This is the case for water drops on leaves such as rubber, nasturtium and cabbage; also on very hairy leaves where the hairs act as a cushion and do not allow the impacting drop to reach the actual surface of the leaf cuticle.

While aqueous-based spray drops may bounce from leaf surfaces, the lower surface tension and lower contact angles on leaves of oil-based sprays renders the latter very unlikely to bounce.

Once the drops have impacted, their energy causes them to spread and the position they finally take up will be governed bv their kinetic energy on impact, their surface tension and viscosity and the values of their advancing and receding contact angles[42 43]. With large drops (500 μm and above) most of the impacting energy is used up in overcoming the viscous forces involved in deforming the drop and the surface area covered when the drop has reached equilibrium tends to be governed by the value of the receding contact angle. With small drops (100 μm or less) the impacting energy is very low, even when the drops are carried in an airstream, and the surface area covered at equilibrium is governed entirely by the value of the advancing contact angle as given by the expression

$$\text{Area of spread drop, } A = 4\pi r^2 \left[\frac{4\sin^3\theta_A}{\{1-\cos\theta_A\}^2\{2+\cos\theta_A\}}\right]^{2/3}$$

where r is the radius of the initial drop, and
θ_A is the advancing contact angle.

Spreading is an advantage in low volume sprays since it increases the effective coverage of the target by the spray. Leaf surfaces vary considerably in the ease with which they are wetted by water; values of the advancing contact angle can vary from about 70° to 140° and the receding contact angle from zero to 130°[44]. The addition of wetting agents such as sodium dioctylsulphosuccinate brings these values down considerably and thus improves coverage[45]. In general, oils have very low contact angles on leaf surfaces and are thus very efficient at spreading over leaf surfaces to provide good coverage.

However, when both the advancing and receding contact angles are low, the retention of spray on the target is poor. Although many factors are involved determining the quantity of spray that may be retained on a surface, a simple theory has been evolved to describe the condition of maximum rention in terms of the surface properties of the spray liquid/solid system, the angle of tilt of the surface and the density of the spray[46]. Other factors that are also important include the spray droplet size[47 48] and impaction velocity, the roughness of the target surface, the size and shape of the target[47], the rigidity of the target and such physical properties of the spray as viscosity and volatility. The effect on retention of the surface properties of the spray liquid/solid system can be examined using a simplified form of the retention equation given by the expression[44]

$$F_R = \theta_M \left[\gamma\left(\cos\theta_R - \cos\theta_A\right)/\rho_L\right]^{1/2}$$

where F_R is the formulation retention factor, θ_A and θ_R are the advancing and receding contact angles respectively, and θ_M is an intermediate value between θ_A and θ_R; for the purposes of comparing formulations θ_M has been taken as the arithmetic mean of θ_A and θ_R.

The effect on retention of a change in the surface tension is straightforward as the retention is proportional to $\gamma^{\frac{1}{2}}$. The effect on retention of changes in the contact angles is rather more complex since it depends on a combination of two factors, firstly the magnitudes of θ_A and θ_R because the retention varies with their mean and secondly, the difference between θ_A and θ_R (the contact angle hysteresis).

With aqueous-based sprays the retention of spray on different leaf surfaces can vary enormously as the values of θ_A and θ_R vary. With oil-based sprays the retention will almost always be low since both θ_A and θ_R are very low.

Conclusions

The physical behaviour of sprays is very complex and it is dangerous to generalize on their performance. However, the preceding discussion has indicated certain physical properties of sprays that are highly desirable under various conditions of application. If spray applications are broadly divided into high, low and ultra-low volume, as defined in the introduction to this paper, it is possible to suggest the most appropriate spray fluid to use in each type of application. This has been attempted in Table 4 although it must be pointed out that the selection is based solely on the physical parameters discussed in this paper. There are many other factors that control spray performance and, for any specific application, there is frequently a conflict between the ideal requirements so that a compromise has to be found and this may make the generalizations in Table 4 inappropriate. Also, although the comments on aqueous-based sprays in this paper have been directed to the behaviour of oil-in-water emulsions, they apply equally well to other types of aqueous sprays, such as wettable powders.

TABLE 4

Most appropriate spray fluids based on physical properties, for various methods of application

Type of Spray	*Type of Application* *High Volume*	*Low Volume* *Ground*	*Aerial*	*Ultra-low Volume*
Aqueous based (o/w emulsions)	+++	++	+	
w/o emulsions		+	++	
Heavy oil-based				+++

The following comments are presented in an attempt to justify the generalizations made in Table 4.

High Volume Spraying. The large volumes of spray fluid involved rules out oil-based sprays on grounds of cost. Also, the low advancing and receding contact angles of oils on leaf surfaces would cause excessive losses of oil-based sprays in run-off. Because of the large volumes, drop sizes can be kept high and so evaporation and spray drift should not be important.

Low Volume Spraying. To maintain good coverage of the target smaller drops than those used in high volume

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spraying are necessary and they should be capable of spreading on impact. However, the spray volumes employed still make it more economic to dilute the spray with water rather than to use oils alone. Good spreading can be achieved with water-in-oil emulsions and also with oil-in-water emulsions, provided an efficient wetting agent is included where necessary in the latter case. Using small drops, evaporation may be a problem but it is less likely to be troublesome when using ground equipment than when applying sprays from aircraft. Ground equipment can be used that projects the drops at the target so that the life-time of the drop tends to be shorter than it is when released from an aircraft. Thus, good retention of spray can be achieved with oil-in-water emulsions from ground equipment but water-in-oil emulsions may well be better from aerial sprays, except under very humid conditions. Where spray drift is hazardous, very viscous water-in-oil emulsions will be preferable for use with both ground and aerial equipment.

Ultra-low Volume Spraying. With the very low volumes and small droplets involved, the main essential is a spray fluid with the very low vapour pressure that only heavy oils are likely to provide. They also have a good spreading ability which is a further desirable property.

THE FUTURE OF HYDROCARBON OILS

The pesticidal spray oils have been used for a long time and they are likely to be used, at least for limited purposes, for a long time yet. Because of the resistance of some pests to synthetic pesticides they may tend to replace the latter, for example in mite control[49]. However, in view of the rapid developments in both chemical and biological methods of pest control it seems unlikely that pesticidal spray oils will significantly increase in importance though they should maintain their share of the market at least in the short term.

There are more significant changes likely in the use of oils as carriers for synthetic pesticides. The general move towards applying smaller and smaller volumes of spray is likely to continue owing to the greater ease and efficiency of low volume application over high volume application coupled with an increasing use of aerial spraying in which the effective pay load is a most important factor in economic operation. Provided the problems of environmental contamination can be overcome the application of ultra-low volumes is likely to increase, particularly if a wide range of pesticides can be made available in suitable formulations; this means that the future will see an increased use of low-volatile oils. From their physical characteristics it would be expected that water-in-oil emulsion will be used to an increasing extent in low volume spraying. However, these emulsions are still in an early stage of development as agricultural sprays and the extent to which they will replace aqueous-based sprays for low volume application is still an open question. The dominance of oil-in-water emulsions in aqueous-based sprays has diminished somewhat over the last few years owing to the development of good wettable powders. This trend is likely to continue since many of the newer toxicants are not very soluble in hydrocarbon oils and the trend will be accentuated if satisfactory water-based suspension formulations, the flowable pastes, can be developed.

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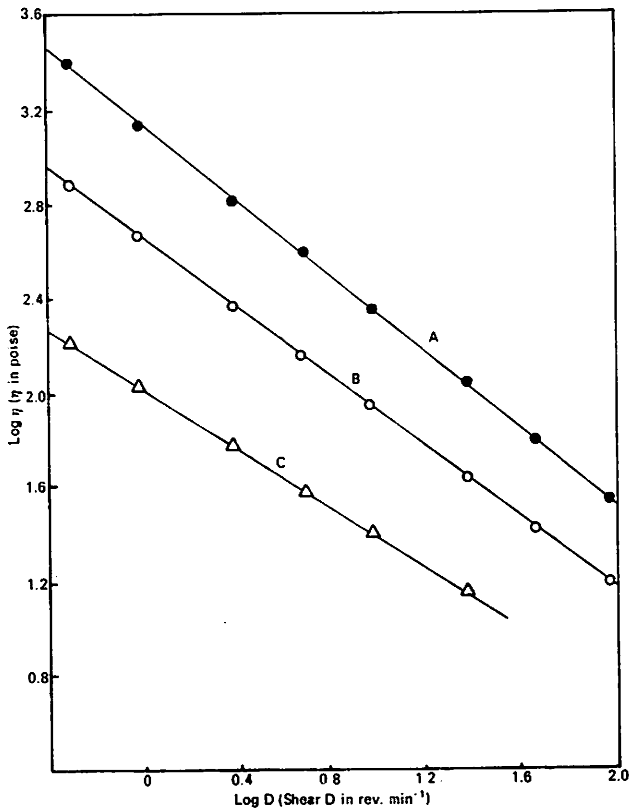

Fig. 1—Variation of viscosity with shear for a herbicidal water-in-oil emulsion.

Curve A, 14:1 water: oil ratio
Curve B, 10:1 water: oil ratio
Curve C, 5:1 water: oil ratio

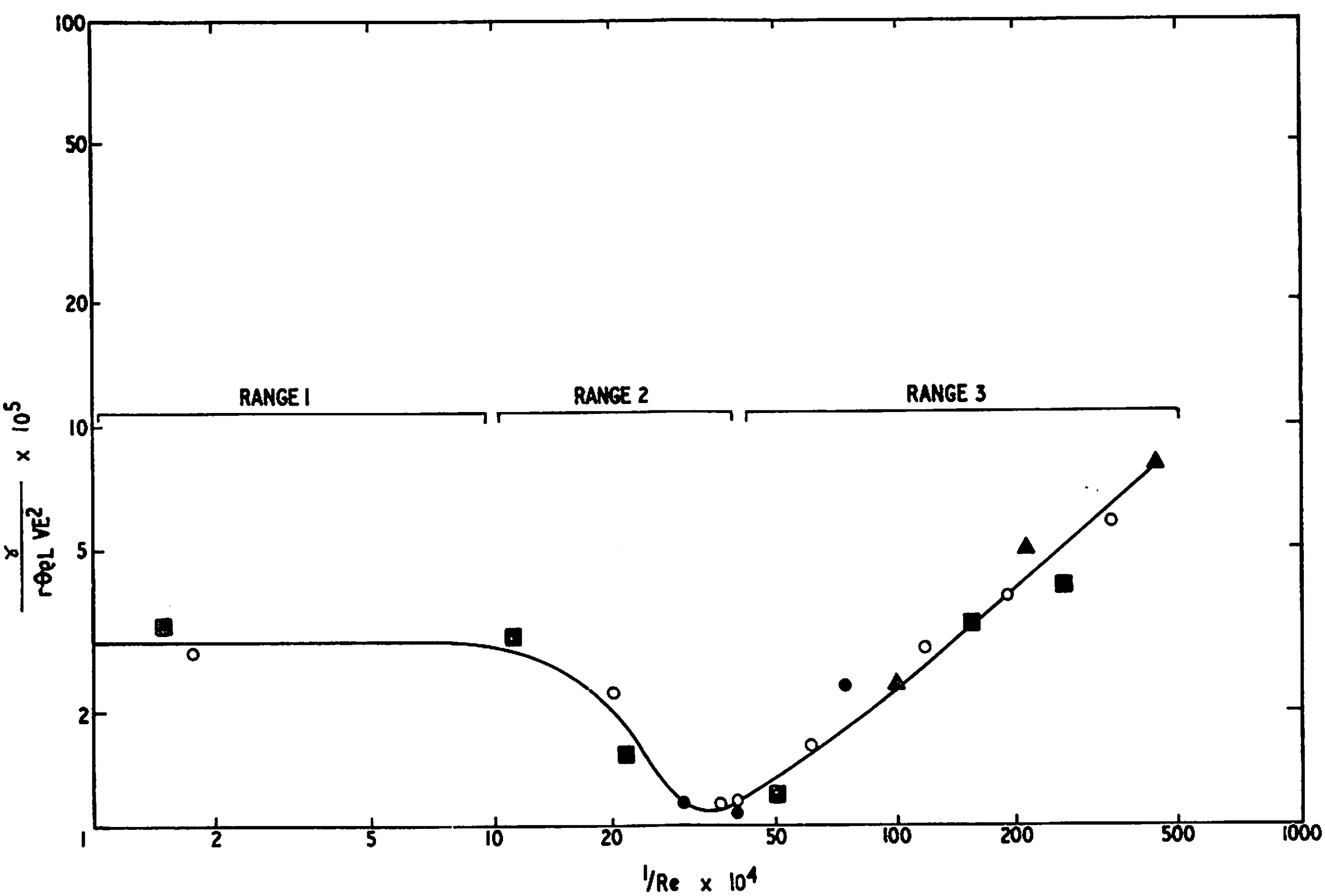

Fig. 2 Variation of $\frac{\gamma}{r\theta\rho_L V_E^2}$ with $\frac{1}{Re}$ for various Allman fan jet nozzles with eliptical orifices.

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THE USE OF HYDROCARBON OILS IN AGRICULTURAL SPRAYS

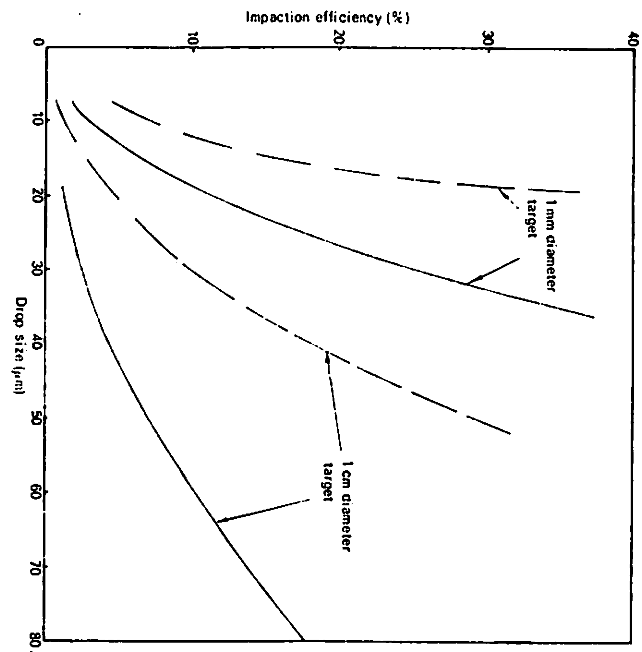

Fig. 3—The efficiency of impaction of small drops (as deduced by Courshee[37] from the results of Jarman[38]).
——— wind speed 1 m/s
.... wind speed 4 m s
Efficiency is defined as the ratio of drops that impact over drops that would have impacted if they had not been deflected from their original course.

PETROLEUM PRODUCTS IN SOIL CONSERVATION

by

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Presented at the Annual Conference of the Institution in London on 9 *May* 1968

SUMMARY

The paper describes the use of petroleum products in the restoration of eroded land. Soil erosion, its causes, and cure by the establishment of vegetation, are very briefly described. The use of petroleum products, in particular bitumen, to stabilise a drifting soil surface during the establishment of vegetation, constitutes the body of the paper.

The principles of stabilization with petroleum products are outlined and the planting/sowing of vegetation discussed. The petroleum products that have been used to form stable surface films or layers on soils are fuel oil, lubricating oil extract, oil extended rubber, and bitumen. The application of these products is described. The advantages and disadvantages of the equipment that can be used are discussed. The total cost of stabilization with petroleum products, including seed and fertilizer used, is estimated to be about £50 *per acre.*

INTRODUCTION

Soil conservation is essentially the control of soil erosion, the process by which top soil is removed by wind and water faster than it is formed. Erosion occurs when vegetation is sparse or absent and there is little to reduce rain water run-off or break the velocity of the wind at the soil surface. A basic step in the control of erosion and the restoration of eroded land is therefore the establishment of vegetation to curb the effects of wind and water. It is with this aspect of soil conservation that this paper is concerned. The paper sets out briefly the basic principles of establishing vegetation with the aid of petroleum products and describes techniques which have been successfully used. It is hoped that this information will form a basis for those wishing to carry out such work. Erosion prone, sparse vegetation areas, are usually caused by one, or a combination of, the following factors:

(a) Climatic deficiency (e.g. insufficient water; exposure to elements).
(b) Nutritional deficiency (i.e. lack of N, P, K, S, or trace elements).
(c) Bad husbandry (e.g. over-grazing).
(d) Excess of toxic elements in the soil.

It is essential that any scheme for the control or restoration of land affected by erosion be comprehensive; all the contributing causes must be removed. It is virtually impossible to prevent exposure on an arctic tundra or render non-toxic a soil poisoned by industrial waste. On these types of areas vegetation cannot economically be established, and erosion prevented. Where it is economically feasible to establish vegetation, climatic and nutritional deficiencies are removed by irrigation and fertilising, thus making the soil capable of supporting vegetation. Good agronomic practices such as contour cultivation and controlled grazing must, where necessary, be introduced. When these measures have been taken, however, one of the problems in the establishment of vegetation is the continual movement of the soil. This is particularly the case in low rainfall areas with sandy soils which have been subjected to wind erosion. Young trees, shrubs or grasses, planted on a moving soil surface, often die through root exposure or suffocation under deposits of eroded soil. If seeding is attempted, the seeds are wind blown or buried and germination prevented from taking place. A solution to this problem is to reduce soil movement by the application of an 'oil' to the soil surface. Oil made from a variety of petroleum products has been used for this purpose. In stabilization with oil, the oil reduces soil movement by forming a stable film or layer on the soil surface. The life of the stabilized film or layer usually varies from about 6 to 36 months. A combination of weather, new growth, and bacterial action, destroys the oil layer.

STABILIZATION WITH OIL

Provided the soil is capable of supporting vegetation, there are three operations in any stabilization with oil project:

(a) Site preparation;
(b) The planting and/or sowing of the vegetation; and
(c) The application of the oil.

(a) SITE PREPARATION:
Each site will be unique and require individual preparation. Of specific importance is the smoothing of escarpments and other sharp faced ground features

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which could aid in the initiation of erosion. An excessively cloddy surface should be broken up as large clods greatly increase the quantity of oil required to stabilize the soil. If existing vegetation is very sparse and new vegetation is being established from seed, the existing vegetation is probably best removed. This will avoid it interfering with the sowing and oil spraying operations. In other cases existing vegetation should, if possible, be left undisturbed.

(b) PLANTING/SOWING OF VEGETATION:

The selection of vegetation that will grow in the soil and climatic conditions of the area to be stabilized is critical. An agronomist's advice on this should be obtained. *Acacia cyanophyla* and *Eucalyptus camuldulensis* have been planted in sand dune areas receiving more than 6 in. rainfall per annum.

(1). Mixtures of grasses and legumes are fequently used because they are relatively easy to establish. Planting, sowing, and fertilizer distribution are done by conventional means. Seed mixtures and fertilizer depend on the soil condition and future use of the land. In hot climates, planting and/or sowing is usually done in the fall or immediately after the first rains. This ensures moisture in the soil and gives time for growth before the summer or dry season.

In the absence of local technical advice, the following can be taken as a guide for the establishment of vegetation from seed:—

Between 25 and 80 lb per acre of seed mixture containing 20 to 50% by weight of legumes should be sown. Fertilizers containing phosphorus to promote vigorous root growth and nitrogen to promote leaf growth should be applied. The form the fertilizer takes will probably depend on the money available for the project and the state of fertilizer technology in the area, viz:

(i) Advanced Fertilizer Technology and Good Budget:
  5 cwt of 20:10:10 or 16:9:9 (granular grades) per acre

(ii) Average Fertilizer Technology and/or Moderate Budget:
  5 cwt of 10:10:10 or 7:7:7 (granular grades) per acre

(iii) Retarded Fertilizer Technology and/or Restricted Budget:
  5 cwt of 10:10:0. This could be a mixture of superphosphate and ammonium sulphate, local powder blend or semi-granular grade.

Eroding soils are normally deficient in rhizobia. To ensure nitrogen fixation the legumes should therefore be inoculated with a rhizobium with which they are symbiotic within 24 hours of sowing.

Seed mixtures which have been used successfully by the author in areas having about 30 inches of rainfall per annum are:

(i)	Grasses:	Rye (*Secale cereale*)	22 lb
		Phalaris (*Phalaris tuberosa*)	2 lb
	Legumes:	Lucerne (*Medicago sativa*)	5 lb
		Barrel Medic (*Medicago tribuloides*)	½ lb
		Black Medic (*Medicago lupulina*)	½ lb
		Harbinger Medic	½ lb
			30½ lb/ac
(ii)	Grasses:	Wimmera Ryegrass (*Lolium rigidum*)	20 lb
		Highland Bent (*Agrostis tenuis*)	2 lb
		Chewings Fescue (*Festuca rubra*)	4 lb
		Phalaris (*Phalaris tuberosa*)	2 lb
	Legumes:	Clustered Clover (*Trifolium glomeratum*)	10 lb
		Subterranean Clover (*Trifolium subterraneum*)	15 lb
			53 lb/ac

A seed mixture suggested as suitable (2) for sowing on pulverized fuel ash in the U.K. is:

Grasses:	Italian rye grass	8 lb
	S23 Perennial rye grass	8 lb
	S24 Perennial rye grass	20 lb
	Rough stalked meadow grass	8 lb
Legumes:	(Seed must be inoculated with rhizobium bacteria—Allen & Hanburys' Culture 'A' and dried)	
	S123 Broad red clover	5 lb
	Later flowering red clover	7 lb
	S100 White clover	4 lb
		60 lb/ac

Generally it will be found that:

(i) Subterranean clovers, white sweet clovers, lupins, and bent grass, are tolerant of acid soils, and

(ii) Lucerne, medics, and red clovers, are intolerant of acid soils.

Rye grasses are tolerant of both acid and alkaline soils. Rye withstands sand blast well and is probably the best of the sand binding grasses.

(c) OIL APPLICATION

The 'oil' is spray applied. Oil products which have been used include light fuel oils, lubricating oil extracts, oil extended styrene-butadiene rubbers, and bitumen. For spraying in conventional equipment the viscosity of the oil has to be below 100 cSt. This is achieved by either heating the oil or by emulsification, generally the latter. (Fuel oils which have much lower viscosities than the other oils at ambient temperatures can also be sprayed using high pressure spraying machines without heating or emulsification). Fuel oils, lubricating oil extracts, and bitumen, can be applied hot, but this complicates the spraying machinery, some form of heating being required. Normally the cost of emulsification is more than recouped by saving on spraying costs. Emulsification, which is merely the suspension of the oil in globules of about 0.5 to 10 micron size (i.e. 0.00005 to 0.0010 cm) in water, requires specialist equipment, and the oils are normally bought ready emulsified from the manufacturer. The emulsions usually contain between 40% and 65% oil and 60% and 35% water. Rubbers are always supplied and used in latex (i.e. emulsion) form. Oil-water emulsions after application 'break' on the soil surface, the water evaporating or percolating into the soil, leaving the oil globules to coalesce on or near the surface. Usually only a surface skin is formed. The depth to which the oil penetrates the soil can, however, be increased on sandy soils by increasing the amount of water in the emulsion. This allows a stable surface layer rather than skin to be formed.

(Bitumen emulsions are also used in soil conservation to tie down straw mulches. The straw mulch is applied at 1½ to 2 tons and bitumen emulsion at about 500 gallons per acre. This type of treatment is well known and is outside the scope of this paper.)

The rate of application of the oil should be such that:

(i) The soil is not sealed (i.e. the ingress of water prevented), and

(ii) The soil is stabilized until growth is established.

Too heavy an oil application and (i) is not achieved. Too light an oil application and (ii) is not achieved. Typical oil application rates which have been used are:

Oil	*Application Rate*
Fuel Oils:	100 to 150 gal/ac
Lubricating Oil Extract Emulsions (60% Extract):	500 to 1000 gal/ac
Rubber Emulsions (40% 'Rubber')	100 to 200 gal/ac
Bitumen Emulsions (60% Bitumen)	150 to 700 gal/ac

Emulsions are usually applied diluted with up to 10 parts of water to 1 part of emulsion to give better coverage as well as greater penetration of the oil into the soil. To allow flexibility in the water that can be used for dilution, the emulsions are normally made as stable as possible (i.e. resistant to the chemical content and pH value of the water). The amount of dilution is, of course, limited by the quantity of fluid that can be economically applied.

A wide variety of spraying machines can be used to apply the oils. The spraying machinery should be such that:

(i) It can be readily moved over the terrain being treated

(ii) The sprayer tank is large enough not to require too frequent filling, and

(iii) If an emulsion is being sprayed the pump(s) used to handle or spray the emulsion do not prematurely coagulate the oil fraction globules causing blockage of the filters or jets.

Oil application rates are such that except on small areas, sprayers with the capacity of the types used in road making (pump outputs up to 100 gallons per minute; spray bar pressures 30 to 60 lb/in^2) are required. Spraying is normally by positive pumping, this being preferred to compressed air (liquid displacement) pumping. Gear pumps are frequently used.

It is the author's experience that in soft sandy soils or sand dune terrain, sprayer tanks between 200 and 400 gallons capacity are the maximum size that can be conveniently handled. For efficient sprayer operation (say one filling of the sprayer tank per acre sprayed), this limits spray application rates to about 400 gallons per acre maximum (e.g. 200 gallons of oil emulsion diluted 1 to 1 with water and applied at 400 gallons per acre), in soils or terrain of this type. For applications such as the stabilization of road embankments where large capacity tankers can be easily supported near the area being stabilized, this restriction does not apply, and very heavy spray application rates can be used if desired. Sprays can be applied by spray lance or spray bar. Spray lance application is only economic for small areas, but is necessary for spraying around planted or existing vegetation which might be damaged by oil. For seeded areas tail spray bars centred on the spraying vehicle are best on 'hard' soils (say where heel imprints are less than 1½ in. deep). Offset spray bars followed by a roller or harrows to obliterate track marks may be necessary on 'soft' soils. Offset spray bars should be articulated to give good spray coverage. (See Figures 1 to 4.) Articulation is not so important with centred spray bars unless these are over ca. 15 feet long. Spraying vehicle speeds between 1 and 3 mile/h are typical. Fan jets which allow higher spraying vehicle speeds and are more robust than cone nozzels are best. Individual jet capacities are up to 4 or 5 gallons per minute with double or triple overlap coverage. For most application rates and sprayer speeds, jets with over 1 gallon per minute capacity relatively widely spaced on the spray bar (say 12 in. to 18 in. centres) are to be preferred because they are less likely to block than smaller capacity, smaller aperture jets at closer centres.

A spray gun or lance with a length of flexible hose is a useful attachment to the spray bar for patching areas between sprayer passes which the bar spray has missed. Should patching be necessary, this is best done as spraying proceeds (i.e. sprayer stopped and

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patching done at once). It is normally difficult to reverse a sprayer and even if this is possible, double spray application with danger of sealing will result on some areas. A variety of spraying patterns for a bar sprayer can be used. The pattern should be chosen to fit the site topography and the spray bar. Straight line spraying (Figure 5) is probably the best. This requires a centred spray bar or offset spray bars fitted on both sides of the sprayer. Spiral spraying (Figure 6) can be done with centred spray bar or offset spray bar fitted to one side only of the sprayer. Provided the site is reaonably level and has no boundary restrictions, spiral spraying will be satisfactory. If there are boundary restrictions to avoid traversing treated areas, it is important to spray so as to work out of the site. If the site is sloped, spraying is best done straight-line up and down the slope. Spiral spraying would involve crossing the slope, which if steep, could result in side slip of the sprayer.

Bitumen emulsions are sold in most areas for road making and are generally readily available. As they are therefore the most widely used of the oil products for stabilisation, the following details are noted on their application. A stable bitumen emulsion should be used. The emulsion can be anionic or cationic, the former normally being cheaper.

The emulsion should be applied diluted 1 to 1 with water at 300 to 400 gallons per acre (i.e. 150/200 gallons emulsion plus 150/200 gallons water per acre). This rate of application will be satisfactory in almost all areas. On road embankments and other areas, subject to heavy rain water run-off, the bitumen emulsion should be applied undiluted at up to 500 to 1,000 gallons per acre. (With bitumen emulsion at application rates over 400 gallons per acre, it is not necessary to dilute the emulsion to obtain good coverage.) At close of work each day the spraying system should be flushed out with water. All filters and jets should be removed, cleaned, and left in kerosine overnight. Diluted emulsion should not be kept in the sprayer tank overnight as it has a tendency to 'break' (i.e. for the bitumen particles to coagulate). This could cause filter or jet blockages. The author has found that all grasses including broadleaved seedlings (e.g. clovers), penetrate bitumen films of the thickness produced by the above rates of application. Soil temperatures below the film are sometimes raised because of the increased absorption of solar heat by a dark surface. The temperature increase has been reported to be as much as 20°F. over untreated soil. Generally the temperature increase varies between 0 and 8°F. in a Mediterranean climate. This will not normally be sufficient to scorch growth and in fact may aid seed germination.

COSTS

The cost of stabilization with oil projects varies considerably from site to site. If vegetation is being established from seed, the material costs will be about £35 per acre, viz:

			£	s.	d.
Seed 50 lb/ac	× 5/- per lb	=	12	10	0
Fertilizer 6 cwt/ac	× 30/- per cwt	=	9	0	0
Oil Say 180 gal/ac	× 1/6 per gal	=	13	10	0
			£35	0	0

The 'application' costs of preparing the site, sowing the seed, distributing the fertilizer, and spraying the oil, are more difficult to assess. The plant and men required to treat 10 to 15 acres per day when working on a large scale could be:

PLANT:

(a) 3 No. Small Bulldozers or Tractors (to pull diamond harrows, disc drills, and sprayer).
(b) 1 No. 400 gallon sprayer.
(c) 1 No. 1000 gallon water storage tank (for water storage for emulsion dilution).
(d) 1 No. Disc Drill (for seed and fertilizer distribution).
(e) 1 Set Diamond Harrows (for site preparation).
(f) 1 No. Lorry.
(g) 1 No. 5 hp Pump (to transfer oil from drums to sprayer and fill water storage tank).
(h) 1 No. $\frac{1}{2}$ yd^2 Concrete Mixer (for mixing seed and fertilizer if applied together).

MEN:

1 No. Foreman
3 No. Bulldozer/Tractor Drivers
1 No. Lorry Driver
5 No. Labourers

10 No. Total

This will give an application cost of about £15 per acre and a total cost for this type of treatment of about £50 per acre. If planted vegetation and lance spraying are used, the costs would probably be higher.

ACKNOWLEDGEMENTS

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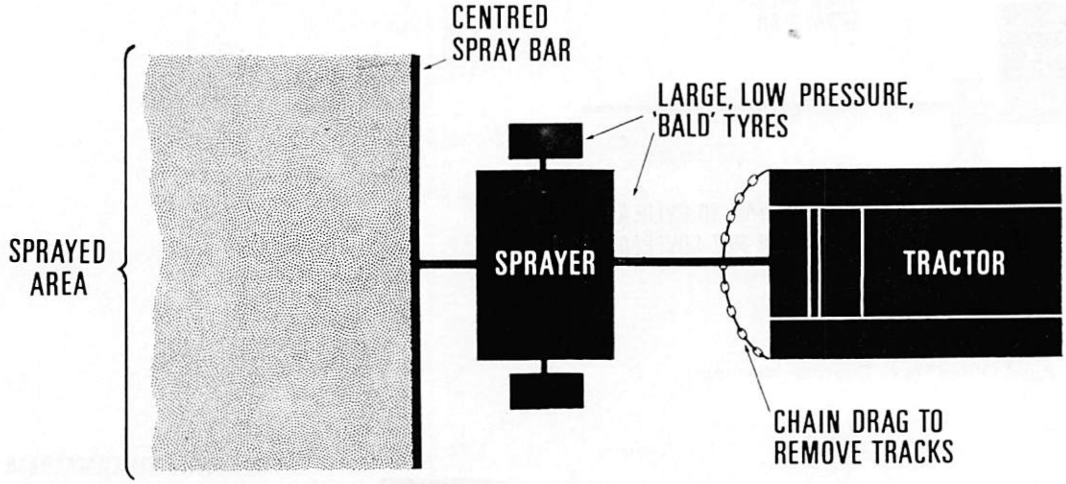

Fig. 1

Spraying arrangement 'hard' soil—Centred Spray Bar (plan

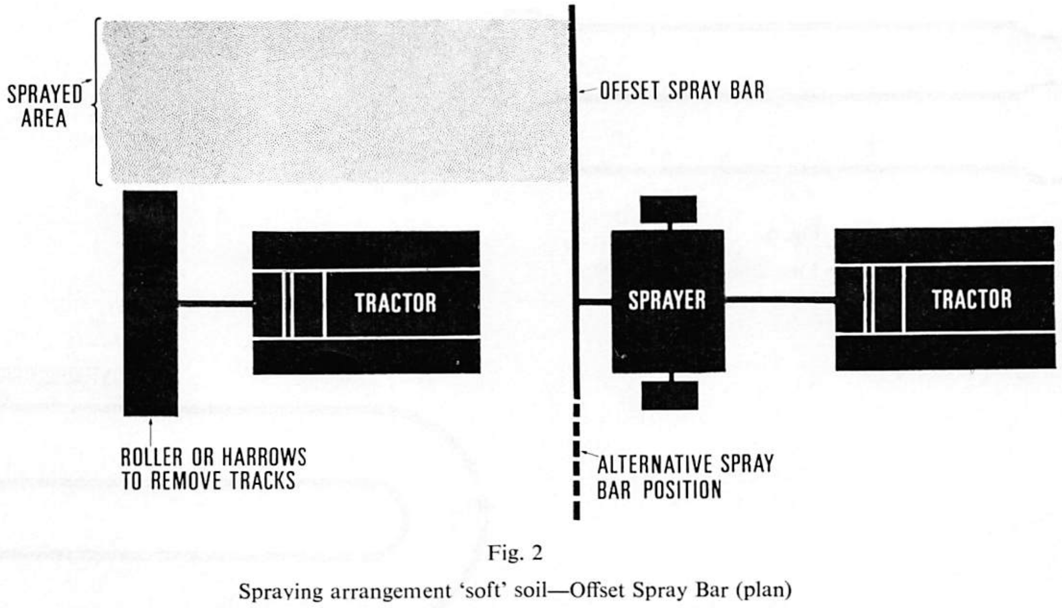

Fig. 2

Spraying arrangement 'soft' soil—Offset Spray Bar (plan)

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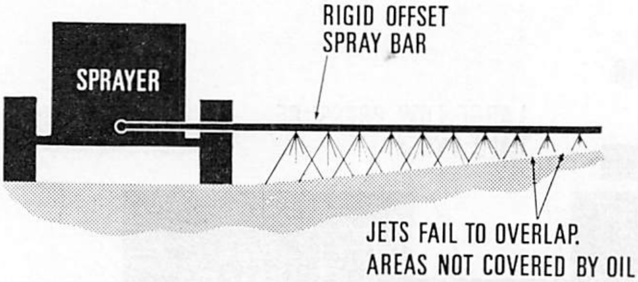

Fig. 3

Rigid Offset Spray Bar (rear elevation).

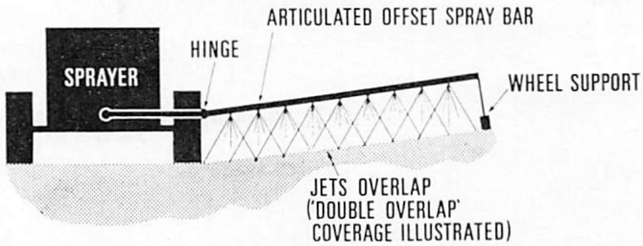

Fig. 4

Articulated Offset Spray Bar (rear elevation).

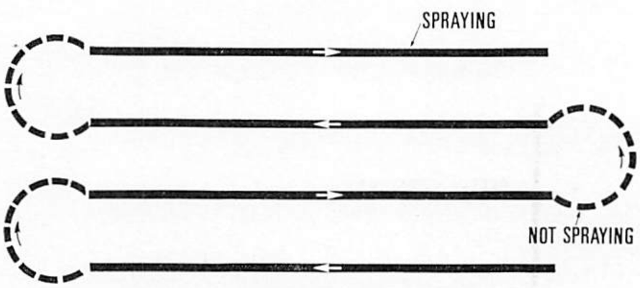

Fig. 5

Straight Line Spraying

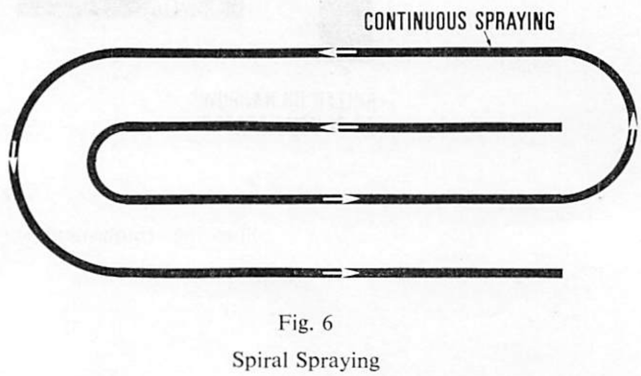

Fig. 6

Spiral Spraying

Publications Received

The following publications have been added to the Institution Library.

Feed Preparation—Farm Electrification Handbook No. 14 —by The Electricity Council Marketing Department.

The handbook contains a great deal of new information, particularly concerning the rolling of cereals, continuous flow milling and mixing and pelleting machinery.

International Directory of Agricultural Engineering Institutions 1968—by the Food and Agricultural Organisation of the United Nations.

The directory is an up-to-date issue of the last edition published in 1962. The material has been collected from 108 countries and has been prepared by H. J. Hopfen, Technical Officer. In the first part names and addresses of central government services are listed, as well as international and national institutes dealing with land and water development, farm power and machinery, rural electrification, farm buildings and farm work organization. In the second part national associations of farm machinery manufacturers are listed, and finally exhibitions, periodicals, textbooks and films dealing with agricultural engineering.

Farm Implement Buyers' Guide—by Farm Implements and Machinery Review.

The edition has been carefully revised and additional pages of information included to provide an up-to-date reference for all sections of the farm implement and machinery trade at home and overseas.

Grain Drying with Supplemental Heat—from the Swedish Institute of Agricultural Engineering.

Designed to provide the farmer with practical advice and instructions regarding the planning of installations for slightly warming the air for drying in cold air dryers for grain. The publication and the installation instructions as based on the Swedish fire protection regulations.

Electricity Information Service Agriculture & Horticulture 1968-69

Useful catalogue briefly describes the various publications, films, etc. giving information on the use of electricity for Agriculture & Horticulture.

Agricultural, Horticultural and Forestry Industry Training Board

Summary of Training Grants Scheme 1968-69.

The Association of Agricultural Education Staffs of Local Authorities

Commentary entitled 'The Training of Agricultural Service Engineers'.

Farm Buildings Progress—by The Scottish Farm Buildings Investigation Unit

A synopsis of farm buildings developments and a report of progress on the unit's projects.

The Unit is responsible for the co-ordination of farm buildings investigation work in Scotland.

Abstracts of Romanian Technical Literature—by Central Institute for Technical Documentation.

The Central Institute based in Bucharest acquires technical and economic information and maintains a large agricultural section.

The abstracts are well designed, informative and printed in English. Copies of the abstracts may be obtained from Bucharest, Calea Victoriei 100.

'Farm Mechanization & Buildings'

We are informed that 'Farm Mechanization & Buildings' has been merged with Power Farming. The first issue of the enlarged, combined journal under the title Power Farming was published in January, 1969, by Farmer and Stockbreeder Publications Ltd. 'Farm Mechanization' was first published in 1946 and merged with 'Farm Buildings' in 1967.

Mr Anthony C. Williams, MIA AGR E, editor of FMB for the past 11 years, who is a Vice-President of the Institution, has been appointed consulting editor (farm machinery), Farmer & Stockbreeder Publications Ltd. whose journals include Farmer & Stockbreeder, Power Farming, Agricultural Machinery Journal (incorporating Farm Implement and Machinery Review), Farming News (Scotland) and Poultry World. He will, therefore, be maintaining his association with farming and farm machinery.

The editorial staff of FMB are being transferred to the new Power Farming, of which Mr Stanley Farmer will be editor, and the services of specialist-contributors will be retained.

OBITUARY

The council records with deep regret the death of the following members:

NOLAN, W. J.	Hon. Member
BROCKETT, G. F. ..	Member
DOWNING, W. W. W.	Member
SLATER, J. K. W. ..	Member
CHARLTON, G. K. ..	Associate Member

ENGINEERING ASPECTS OF AMMONIA INJECTION AS DEVELOPED IN FRANCE

by

JEAN CAUPIN

INGÉNIEUR ENIA*

Presented at the Annual Conference of the Institution in London on 9 May 1968

SUMMARY

Ammonia injection used directly as nitrogen fertilizer for all crops on arable lands and pastures was started in 1961 in France, and the sales reached 20,000 tons during the season 1966/67, i.e. about 2% of the French nitrogen consumption.

A rapid growth in demand is expected, as experience has shown in the U.S.A. and Denmark where anhydrous ammonia was started earlier.

In these two last countries, ammonia represented in 1966/67 more than 30% of the nitrogen used in agriculture.

The big problems with ammonia—which in the past confused the issue—were only engineering problems. *The equipment has progressively improved to meet the worst conditions which can be encountered in more ingrate soils of Europe and elsewhere.*

The author describes the equipment designed and developed in France from the moment ammonia leaves the producing plant up to the injection in the fields.

The aim was to incorporate ammonia injection in the normal mechanized farming routine for all crops and pastures. Equipment must permit two jobs to be done at a time, so when required ammonia is injected with the plough, cultivator, roller, disc harrow. Several devices had to be designed to make the equipment more easy to use: complete safety in transfer of ammonia, accurate metering, and avoiding losses of ammonia, were some of the problems solved.

The author shows that fertilization—first tool of the farmer—can be greatly improved by the new method, which is in line with the latest ideas about progress in agriculture, and permits other improvements.

Introduction

France, with more than 80 million acres (two-thirds arable land, one-third pasture) of useful agricultural surface cultivates as much as the five other countries of the Common Market together. This is due to the fact that 60% of the total surface of the country (140 million acres) is used for agriculture, the highest percentage by far in Western Europe. There is so much acreage available in our country that the definition of 'good soil' is not the same as elsewhere, since some soils that we consider as not being proper as arable land are used heavily in other countries, due to the scarcity of cultivated soil and higher density of population.

The fact that we are in a country agriculturally 'blessed by the Gods', with 17% of the population still employed in agriculture—as against half or less in other advanced countries—does not on the other hand produce the basic incentives that are necessary for the development of a new nitrogen fertilization technique like ammonia injection. Further, the average use of nitrogen is only 24 units of N/acre for the 80 million acres, and is as low as 5 units of N/acre average on the 30 million acres of pasture, whereas injection of ammonia in the soil is only justified when at least 65 units of N/acre are required in one application (British units).

However, France was a very good experimental ground for the new technique in Europe, and no country can draw more advantages than she can out of the idea, at a time when hunger in the world requires all available land to produce surplus food.

Our country used 950,000 tons of N for agriculture in 1966/67. Five ammonia plants of 1,000 ton/day—now starting up or under erection at strategic points—will supply, when working at 60% capacity, all present requirements. As five further new plants and more will be soon in operation in France or at its borders, the future available production, with over 3 million tons of ammonia per year, i.e. 2.4 million tons of N, will be ample to supply the anticipated doubled use of nitrogen within a few years.

A solid basis therefore exists for development of the new techniques, and also an ample supply of ammonia; in fact much more than can be reasonably transformed into solid fertilizer. It was therefore natural that a small

* President, L'Ammoniac Agricole

group of pioneers decided, nearly ten years ago, to put ideas into practice. They were joined progressively by the largest French companies.

A map of France (prepared by the French Syndicate for Nitrogen—SPIEA) showing the total use of nitrogen per department (corresponding to the size of a county) is available together with a map showing the location of the Ammonia Service Stations (see Figures 1 and 2). Service Stations are placed where the largest quantities of N are used.

A study of the growth in the use of ammonia for agriculture during the first eight years (see Figure 3) discloses comparatively lower growths in the early years in the USA and Denmark. These two countries now use more than 30% of total N as injected ammonia and will be tending to use 50% within a few years. Figure 4 reflects the five-year change in the USA between 1961/62 and 1966/67 for direct nitrogen applications. Compound fertilizers, not represented in the chart, represent one-third of total nitrogen used.

As shown in Figure 2, the quantity of ammonia used in France was only about 20,000 tons in 1966/67 and the maximum forecast for 1967/68 is 30,000 tons. This will represent only 2.5% of the total use of N in France. About 500 sales points exist, but they are working below capacity, as farmers are always slow to change their methods. The stations still only serve 5% to 20% of the total nitrogen used in their districts.

The main part of this paper will try to show that *engineering* was the chief problem, and will then examine in the conclusion what are the future prospects for ammonia injection in France, UK and elsewhere, as well as the new ideas emerging.

The Engineering Aspects

The agronomic value of ammonia as a nitrogen fertilizer is now recognized by everybody in France. It took time, but with transport and labour, farm manure nowadays costs perhaps 20 times more per unit of N brought to the soil, whereas the transformation of straw into humus is carried out straight away in the field with the ammonia fertilizing disc harrow, or plough.

The big problems with ammonia—which in the past confused the issue—were only *engineering problems*. The fat and easy soils of France have been, since 1961, a good test bench for the various types of injection machinery required by the European farmer. The equipment has been progressively improved to meet the worst conditions which can be encountered in more ingrate soils of our Continent and overseas.

We shall quickly describe the equipment designed and developed by the leading French firm, starting from the field equipment and following the line upstream to the ammonia producing plant.

The ultimate aim is to incorporate ammonia injection in the normal mechanized farming routine, for all crops and pastures, orchards, vineyards, rice cultivation, etc. In most circumstances, equipment can do two jobs at a time—at the most suitable time for fertilization—and ammonia is injected free of cost, along with the plough, cultivator, roller, disc harrow, and the like.

However, it was not reasonable to try convincing the farmer straight away to use a 'fertilizing tractor', i.e. a tractor permanently equipped for ammonia injection all the year round. This will be a further small revolution in farming practice later.

The first thing to do was to offer to the agricultural contractor, and possibly later to the farmer, 'universal' equipment coupled to the three-point lift of the tractor, to be used in all conditions, even if the job was not perfect. Two basic kinds of equipment were necessary, one for arable land and one for pasture.

The semi-mounted applicator for arable land with a tank containing half a ton of ammonia is the main tool used practically throughout the four seasons. On a pilot farm of 4,000 acres in northern France, it works up to 160 days per year, each day the tractor is in the fields. With a tractor of 50/60 hp, one can work with 11 to 20 coulters at intervals of 1 foot and on a width of up to 16 ft at a speed of 3.5 to 5 mile/h, in a soil which is not too compact. Such equipment covers an average of 25 to 40 acres, and uses up to 2 to 2.5 tons of ammonia per day. With an average of 15 full working days, this corresponds to 30/35 tons of ammonia per applicator and per year. 65% of the ammonia used in France has been injected that way so far.

The mounted applicator for pasture is equipped with six discs to cut the grass ahead of the coulter and with a wheel to close up the soil after, for avoiding losses. It contains one third of a ton of ammonia in the tank supported by the three-point lift but the weight of the tank gives the necessary strength to penetrate the soil of the pasture. With a tractor of 50/60 hp, one works with 5 or 6 coulters at intervals of one foot on a width of 6 ft at a speed of 3.5 mile/h. This equipment covers about 15/20 acres per day—about half the area of the arable tool—but as it is used during a longer period, the quantity of ammonia delivered per pasture applicator and per year is about the same. It can be fitted alternatively with arable land coulters, to suit the needs of the farmers. It is expected that the French farmers will soon discover the advantage of using nitrogen on grass thanks to this equipment, which has a great future as a means for increasing meat production.

These two basic equipments (see sketches of Figure 5) which take full advantage of the three-point lift of the tractor, have all the features required for more specialized tools, and have the following capabilities:

(a) to be used *safely* with all three-point lift tractors;
(b) to work in a great number of different conditions encountered in farming;
(c) to inject ammonia with enough accuracy and regularity, both as regards the quantity of units per acre and the width of the tool;
(d) to ensure a distribution directly proportionate to the speed of the tractor, by the use of a volumetric pump moved by a wheel;
(e) to avoid too rapid wear of the coulters, without clogging of the ammonia pipes by frozen earth. Clogging is easily noticed as all the pipes are frozen white in working normally;

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(f) to inject regularly ammonia at 6 in. depth minimum in arable land, and a little less in pasture;
(g) to measure with sufficient accuracy by means of the level gauge the quantity of ammonia injected in a given field of, say, two acres and above, as the agricultural contractor has to give proof of the work done for the farmer.

The tanks of the applicators are built according to the regulations of the French Administration (Service des Mines) for a maximum working pressure of 280 lb/in^2 and are tested at 420 lb/in^2. These tanks are made of high resistance steel which give a maximum volume for minimum weight, and can withstand a pressure of 1,200 lb/in^2 before deformation occurs.

From these two types of equipment, larger arable applicators are now derived which can inject on a width of 25 ft and cover 80 acres per day with a tractor of 100 hp and more, and a trailer tank of 2 tons. However, the number of farms having enough 80-acre fields—for each day's work of the equipment—is still small.

At the other end, light equipment for farmers with 100 acres using a 35 hp tractor and 4 tons of ammonia per year is now available. The tank contains one-fifth of a ton of ammonia and can be used at the same time as the plough, disc harrow, cultivator, roller, etc. The volumetric (ammonia) pump permits a versatile use of the equipment, which would be very difficult with a simple reducing valve.

At present, more than ten different versions of the equipment exist to meet practically all the requirements of the arable and grassland farmers, and also for orchards, vineyards, ricefields with and without water, etc.

The applicator's tank covers from one to five hours of work in the field, as the quantity of ammonia used can vary from 65 to 350 units of N per acre. Transfer of ammonia in the field from a nurse tank designed to contain one day's work is essential in order to avoid dead times. A safe method of transfer has been found which prevents accidents by a series of controls. Operators work most of the time without masks and gloves, and the handling of the job simply requires the same kind of skill as is expected from a tractor driver. In fact, transfer is made with two pipes (one for liquids and one for gas, with a gas hand pump or a motor driven turbine) with the same facility and relative safety as for petrol, the only difference being that transfer is effected in a close circuit.

The capacity of the nurse tank, standing at the end of the field, is usually 2 tons of ammonia, but can vary from ¾ to 8 tons, according to the daily requirements. The nurse tank fills the applicator tank in about 10 to 15 minutes, up to 85% capacity, required by safety and shown by a simple gauge device. The pressure in the tanks of applicators, nurse tanks etc. never exceeds in practice, 150 lb/in^2 at mid-day, due to the regulating effect of liquid in the tank.

Nurse tanks are filled up at the Ammonia Service Stations which cover a radius of 5 miles, i.e. about 25,000 acres of fertilized land with a potential outlet of 1,000 tons of ammonia per year. The initial capacity of the service station is usually 8 to 12 tons in 2 or 3 tanks of 4 tons, self supporting, easily installed and removable, and for which Government authorizations are simpler to obtain. According to the increase in sales, the volume of the service station is increased, as it must always be 20% to 50% larger than the capacity of the trailer supplying ammonia, which is at present usually 8 tons (2 tanks of 4 tons coupled on a chassis).

The trailer can also be used temporarily as a mobile service station and is filled up from a depot of 60 to 90 tons. The depot is also designed to accommodate railway wagons, and to supply 20 service stations, in addtion to nurse tanks in the vicinity. The depot has a radius of supply of 25 miles, i.e. two journeys per day of the 8-ton trailer.

A coefficient of rotation of 6 (i.e. 6 fillings of a service station) is required from the station after two years of operation with two applicators, the aim being to exceed a coefficient of rotation of 10 after three or four years with four applicators and more attached to each station. Two of the difficulties which had to be mastered were first the short length of the main fertilizing season, as 60% of the ammonia has (so far) to be injected in March and April; secondly the fact that the farmer wishes to have the ammonia tank situated as near as possible to his farm in order to be able to work within one hour of his decision, according to the weather.

The new 1,000 ton ammonia-producing plants in France are luckily situated in the regions using large quantities of nitrogen. Transport to the depots within a radius of 125 miles is made mostly by 18-ton trailers, making one to two journeys per day. Alternatively, transport is affected by rail, in trunk wagons—although they are not so rapid or flexible as trailers—but can serve usefully as extra storage capacity in the peak period, and for remote places.

The top requirements of the ammonia injection business come exactly at a time when the solid fertilizer units slow down their activity and consume less ammonia, as all their orders for the season's campaign have to be delivered by the end of February. They thereafter start stocking for the following year. The requirement of the ammonia distributing firms therefore matches very well with the need of the ammonia plants, and these work continuously 330 days per year if possible.

With the new 1,000 t/day plants, substantial refrigerated storage of from 10,000 to 30,000 tons each to be operated by the French distributing companies may not be required for some years, probably when the share of the ammonia injection business exceeds say 50,000 to 100,000 tons per year. The latest types of refrigerated storage—refrigeration at atmospheric pressure being the safest type of storage—is much less costly per unit of N than the storage of solid fertilizers in the most modern godowns.

Let us again insist on the fact that for all the storage, transfer and transport already mentioned, safety is the essential feature in the design of the equipment. One considerable safeguard for pressure equipment on the road arises from the fact that the tanks are designed to withstand a pressure of 420 lb/in^2 which amply resists the effects of road accidents. Each piece of moving equipment is re-tested every five years, and every ten years for stations. A safety valve is fitted on each vessel and no filling is allowed above 85% of the capacity of the tank. Hoses are checked with ammonia gas at the same pressure each time before liquid ammonia circulates in the pipe. Thermal shocks are avoided, since hoses are empty of liquid before disconnecting, thanks to an ingenious device using the gas pump or turbine.

Economic requirements for the growing use of ammonia have been clearly defined by experience over a number of years in U.S.A., and more recently in Denmark. We have come to similar conclusions in France. A major problem is that the investment per t/year in the distribution network from the ammonia factory up to the field is about twice as much as the investment in the producing plant, which already necessitates considerable sums. But the main point is that such an investment is justified by the results in the long run, which is essential to satisfy the financial men.

Taking into account all costs, the price of N injected into the soil generally starts about 20% less than with the cheapest solid fertilizer put over the soil. In comparison with injection, surface spreading of nitrogen fertilizers with split applications reveals itself today as a major infirmity in normal soils without big stones, which can stand the tractor's work. When the farmer becomes accustomed to ammonia, he discovers that he can use with profit larger quantities of N together with the 2-1-1 or 3-1-1 NPK formulations. The larger yields he obtains from his field seem to be more important to him than the reduction in price of the nitrogen fertilizer. Therefore there is a tendency to increase the price of ammonia nearer to the price of solids, in return for giving better services to the farmer.

Agronomic requirements of crops are ideally met by the use of ammonia, which is injected at the roots of the plant: both humidity and food are then available at the right place. Gradual release of ammonia to young plants and nitrification by micro-organisms correspond to the natural requirements of crops. After harvest, and spreading of P + K mixtures, injection of 50 units of N with the disc harrow on chopped straw permits its quick transformation into humus by reducing the ratio $\frac{C}{N}$ from 100 to 10 for the ideal proliferation of micro-organisms.

Incidentally, spreading of P + K powder after harvest with cheap 0-20-20 formulas reduces the weight of solid fertilizers by half, as compared to the use of complex fertilizers of 20-10-10 formulation. With 160 units of N per acre, it means a $\frac{1}{2}$ ton instead of 1 ton of fertilizer.

Another great advantage of ammonia injection is the side dressing and top dressing of cereals and row plants, which lengthens the period of application, aerates the soil, and permits feeding the plant at a time which would be impossible with solid nitrogen fertilizers, or if there is no rain in the growing season.

Soil compaction has to be avoided as much as possible in all fields after sowing; again the use of the plough with ammonia gives the best answer which has so far been offered to meeting this problem.

On grass, trials have been made in France with up to 1,200 units of N per acre, and it has been found that the production of proteins could be increased proportionally to the use of ammonia up to about 600 units of N per acre. For economic reasons and to preserve the quality of proteins, it seems advisable for the time being to keep fertilization below the 600 units of N limit. It seems therefore that, within a few years, it will be possible to obtain much more from the nitrogen starved pastures of France. Let us remember that one French unit of N per Hectare (corresponding to 0.8 British units per acre) produces food for one cow per day, equivalent to 1/2 kg. of meat, or 14 litres of milk. Aeration of the pastures by two crossed injections per year is also an improving factor.

Conclusion

In conclusion, let us take a brief look at future prospects for ammonia injection in France, UK and elsewhere. These prospects are good, for the same basic reasons which have brought the development of the domestic and industrial uses of fuel oil as compared to coal, or of jet aircraft as compared to propellor-driven aircraft, etc.

Distribution networks are now established in most Western countries. We see no reason why the rate of growth should be different from that of Denmark, which has been a great surprise to many fertilizer specialists, including those engaged in the ammonia injection business.

The difficulty seems to be to reach a rate of 20,000 tons of sales per year. Afterwards the rate of expansion in France will probably decrease progressively from 50 to 20 per cent towards 100,000 t/year. But an increase of 20% per year in sales is a large proportion when sales are counted in hundreds of thousands of tons, as shown by the example of U.S.A.

It looks as though the increase of sales of injected ammonia in the U.K. might quickly overtake the French sales in spite of our five years advance of pioneer work. May I recall here the excellent team spirit that exists between British and French specialists in this field, illustrated by the great honour I have in speaking to you today.

In the long run, one can forecast that the number of applicators, alone or coupled with ploughs, harrows etc., or permanently fitted on the 'fertilizing tractors' will be similar to the number of combine harvesters in an advanced country. We have now over 100,000 combine harvesters in France, and, as in the case of harvesters, farmers will have a tendency to buy their own applicators to save the 30 Fr/ha (£1 per acre) paid to the agricultural contractor for doing the job on arable land, and 50% more on pasture. Of course, solid fertilizers will for a long time represent the larger share of the nitrogen business, but approaching progressively 50% of the nitrogen need not look absurd for the ammonia injection business.

It can also be forecast that countries overseas and especially developing countries will one day consider

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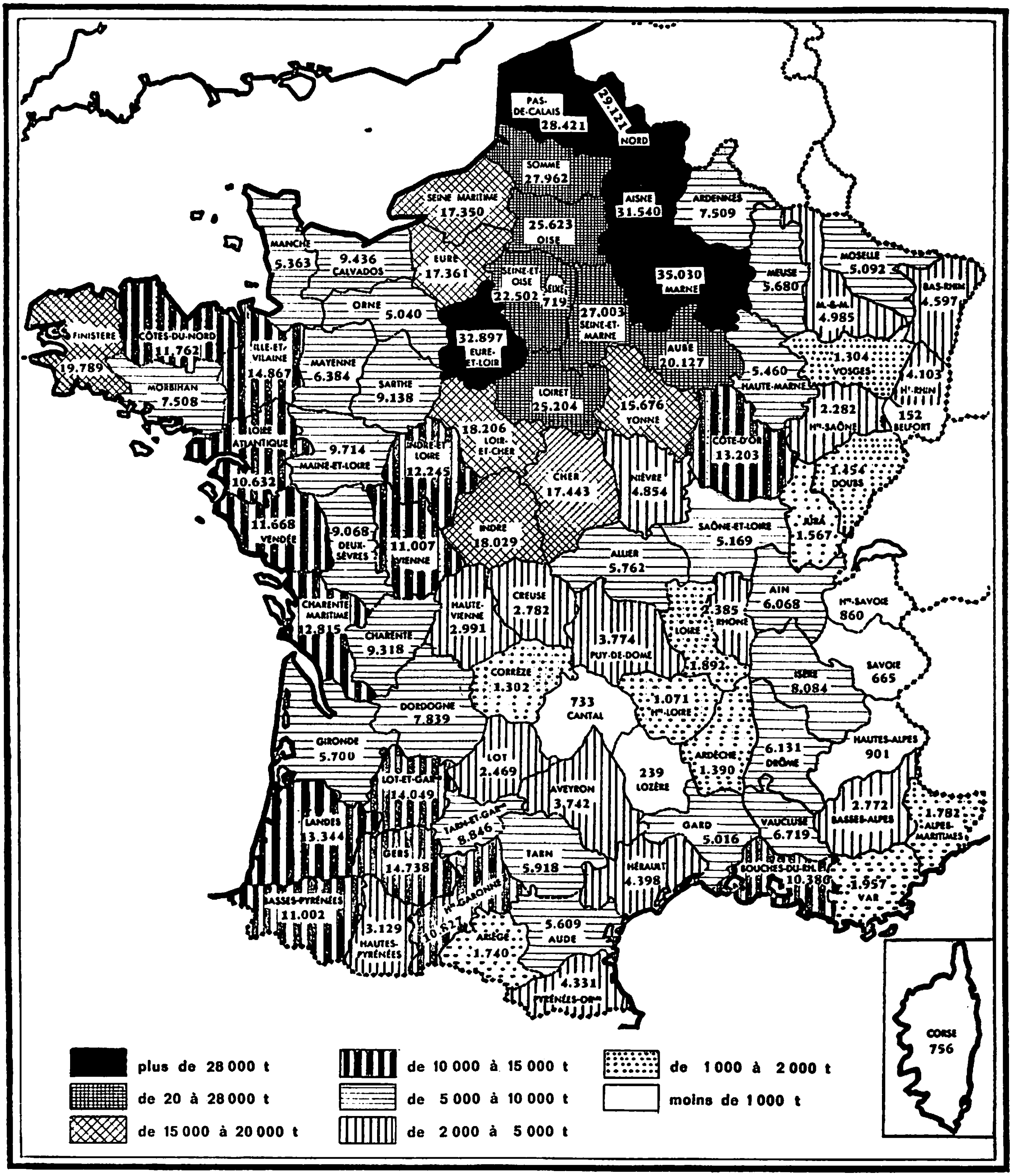

Fig. 1

Allocation by Departments of Nitrogen fertilizer (total fertilizer, Simple and Compound) Season 1965-66

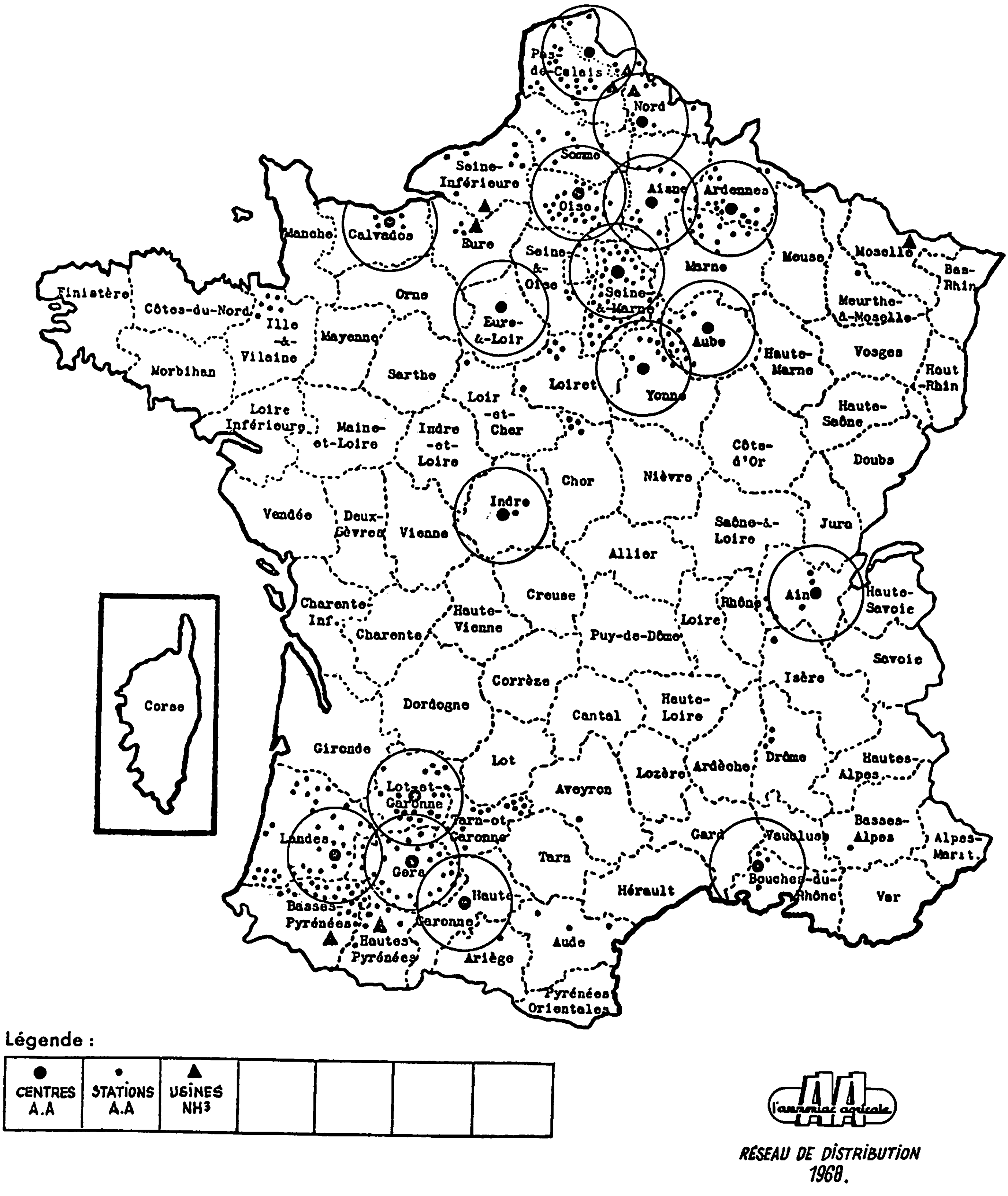

Fig. 2

Distribution Network 1968

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seriously the new technique. Refrigerated ammonia can now be transported all over the world at reasonable prices —a little over the price of petrol in small boats—especially as the fleet of Liquid Petroleum Gas (LPG) tankers which now represents more than 1 million tons is partly idle from March to September, due to the seasonal transport of propane. The future of low value refrigerated methane transport and storage can also be questioned in view of the development of pipe-lines in Europe, and these methane facilities could be quickly converted for ammonia use.

Within three to six months it will become possible to organize with a limited capital investment in a developing country a pilot demonstration with ammonia injection on say 50,000 acres. It requires only a suitable port for the ammonia boat, enough good fields of sufficient size within 100 miles from the port, and the required number of tractors. Once the first demonstration has given results, the scheme can be multiplied year after year, with limited investment due to the saving in the cost of fertilizers.

By comparison, the smallest nitrogen solid fertilizer factory will require £20 millions of investment for an equivalent of 200 tons of ammonia per day plus three years of patience and the education of farmers has still to be achieved.

Various new ideas are coming up with injection ammonia use. Up to now, the choice of the nitrogen fertilizer to be produced was made by chemical engineers, more to serve the rational organization of the chemical plant, also transport and storage of the finished product, than the real needs of the farmer.

With ammonia injection, new avenues are open and we prove that nitrification is more regularly achieved in the soil, free of cost, by the micro-organisms. One wonders whether finely ground rock phosphate could not also be solubilized in the soil in the presence of nitrified ammonia, and whether a similar beneficial effect could not be obtained free of cost with potash.

Interesting trials are also being made with ammonia for such requirements as potato de-haulming, sugar beet leaf removal, etc., to facilitate harvesting. Many other ideas are also on the stocks or under trial to improve the efficiency of the farmer.

Undoubtedly, ammonia injection are two words the farmer and the research people are not going to forget in the years to come.

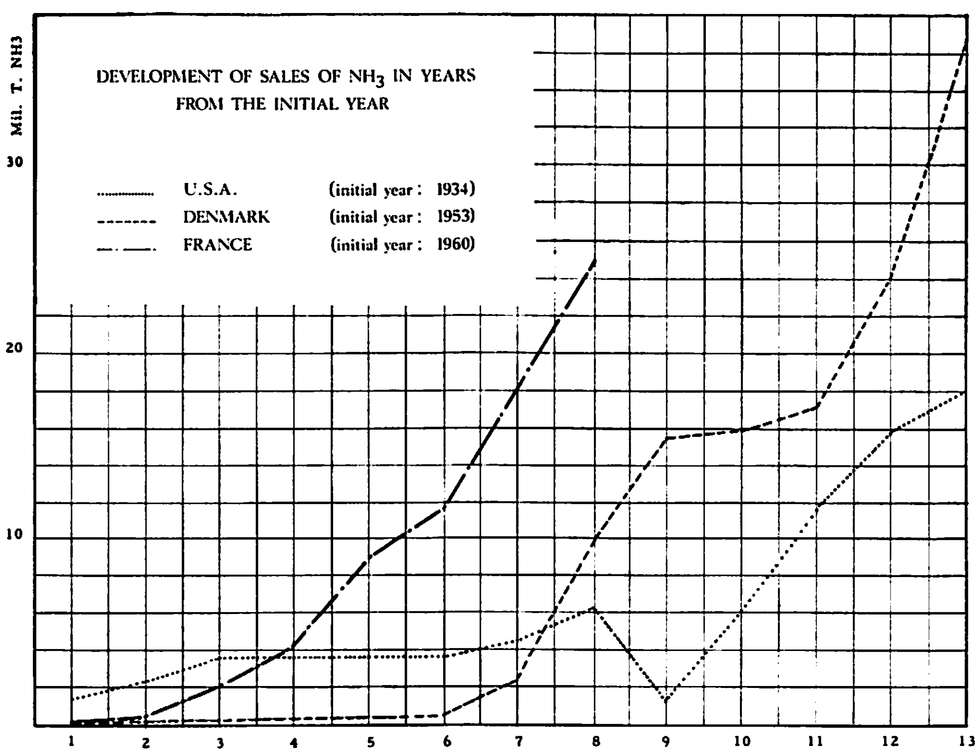
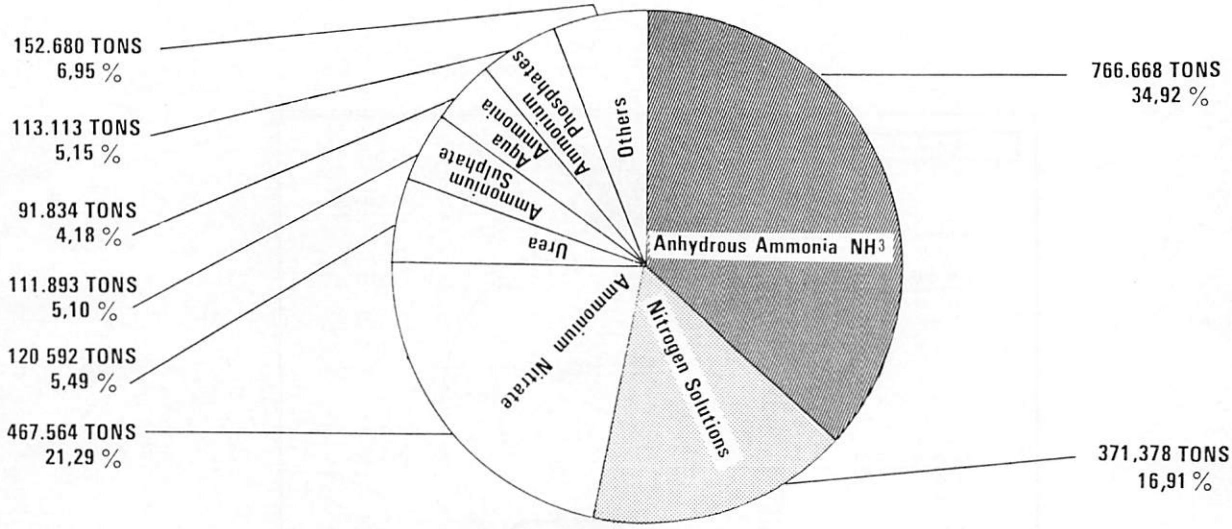


Fig. 3

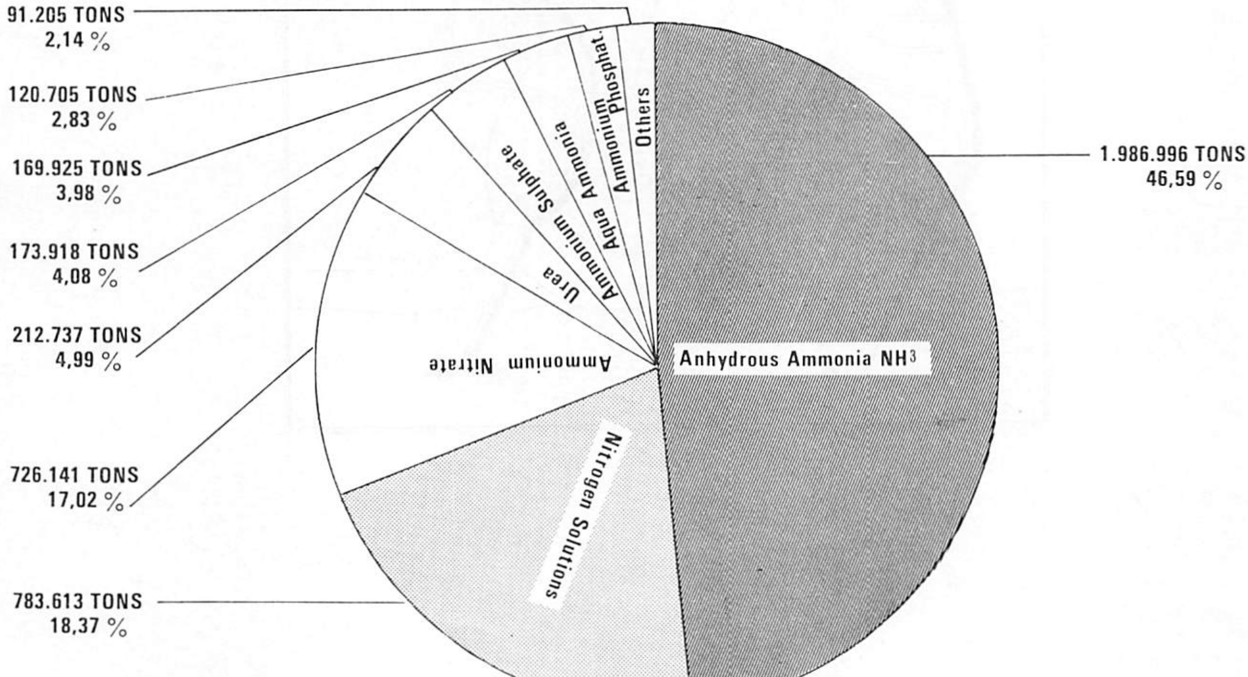
TOTAL TONS AND RESPECTIVE PERCENTAGES OF NITROGEN SUPPLIED BY MATERIALS (for direct application)

(1966-67 versus 1961-62 — Reflecting 5-Year Change)



TOTAL TONS NITROGEN SUPPLIED BY MATERIALS IN 1961-62

(With Respective Percentage Supplied by Each Material Shown)



TOTAL TONS NITROGEN SUPPLIED BY MATERIALS IN 1966-67

(With Respective Percentage Supplied by Each Material Shown)

SOURCE : Preliminary Report "Consumption of Commercial Fertilizer in the States - Year ended June 30, 1967." Nitrogen content of materials in 1966-67 calculated on 1965-66 basis. Alaska, Hawaii and Puerto Rico not included. Tonnages include only those fertilizers supplying one or more primary nutrients.

Fig. 4

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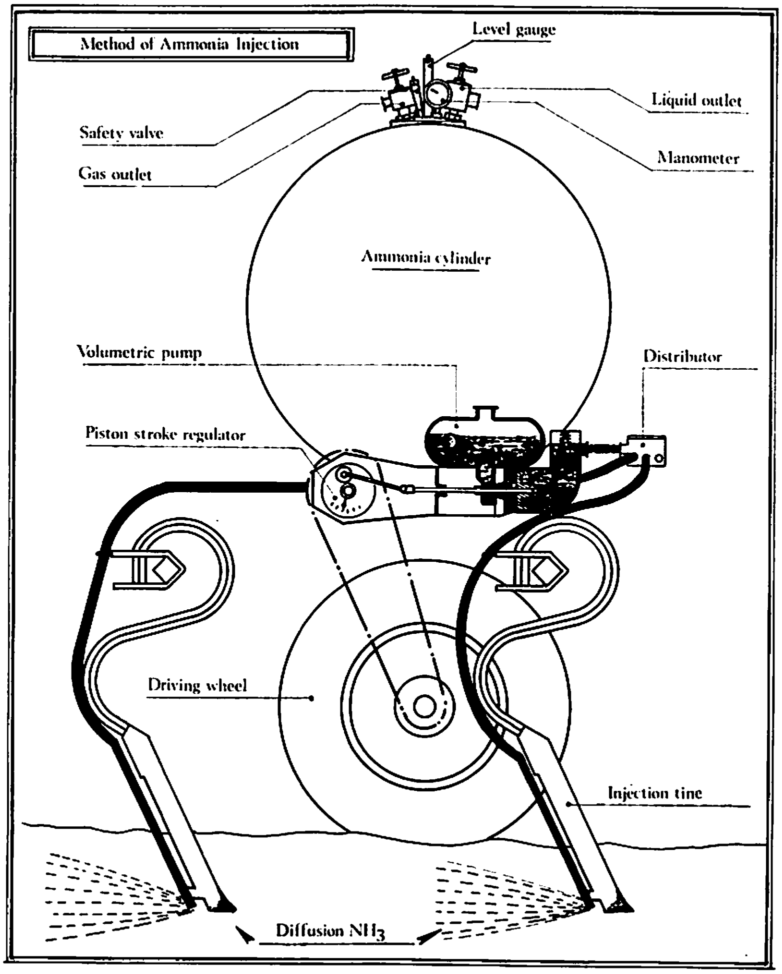


Fig. 5

ANALYSIS OF OILSEED RESIDUES

The series of British Standards reflecting work carried out by the Agricultural Food Products Technical Committee of the International Organization for Standardization (ISO/TC 34), is extended by BS 4325: 1968 *Methods for the analysis of oilseed residues,* which is now published in five separate parts.

The methods concerned are: Part 1 *Determination of moisture and volatile matter;* Part 2 *Determination of total ash;* Part 3 *Determination of ash insoluble in hydrochloric acid;* Part 4 *Determination of oil content* and Part 5 *Determination of diethyl ether extract.*

Each part is technically identical with an ISO method which has been accepted by the ISO Council as an ISO Recommendation or has been submitted for acceptance. The United Kingdom, through the BSI, has taken an active part in the development of these methods.

The methods are intended for use with residues (including cakes and meals, but excluding compound products) resulting from the extraction of oil from oil seeds by pressure or solvent. As these products are among those covered by the Fertilizers and Feeding Stuffs Regulations, 1968, which prescribe methods for the determination of specified analytical characteristics, the application of the ISO methods in the United Kingdom is restricted to purposes which are outside the scope of these Regulations. Parts 1-4 of the standard include as appendices, for information, the corresponding methods prescribed by the Regulations. These differ in detail, though not in principle, from the ISO methods.

Parts 4 and 5 describe closely similar methods for the determination of lipid matter by extraction with a solvent. In Part 4 a hydrocarbon solvent is used; as this method is essentially the same as that for determining the original oil content of the seeds (see BS 4289, Part 4), it is used by oil producers. Light petroleum is also specified in the method prescribed by the Fertilizers and Feeding Stuffs Regulations, 1968. On the other hand, diethyl ether has been widely used by organizations concerned with animal feeding, and as the two solvents do not necessarily yield identical extracts from the same sample it has been thought necessary within ISO/TC 34 to have separate ISO Recommendations for the two methods.

The presentation of the methods follows a standard pattern, which provides for the following technical clauses: definitions, reagents, apparatus, procedure, expression of results, test report. Metric units are used throughout.

BS 4325 may be obtained from the BSI Sales Office at 101/113 Pentonville Road, London N.1, priced as follows: Parts 1 to 4, 5s. each: Part 5, 4s. Postage is extra to non-subscribers. (6d. for one part; 9d. for two; 1s. for three or four and 2s. for 5).

The Question is:

What is the 30-year Anniversary Endowment Fund all about?

Here is the answer from the President:

T. SHERWEN, C ENG, FI MECH E, MSAE, FI AGR E

A powerful Institution of Agricultural Engineers is essential. It is a highly specialized body with its own separate identity and purpose—it intends to stay that way. But its capital reserves are negligible.

This is the first appeal for voluntary support ever to be made during the thirty years of this Institution's active existence. It is not required for current activities or for day-to-day operations. Every pound contributed to this Fund is to be saved, husbanded, invested for the future. It will form part of our armoury for new developments, long-range planning and ultimate survival as an independent body. It will be the Institution's blood bank. It is for tomorrow rather than today.

Thanks to the generosity of several hundreds of members throughout the world, more than £2,000 was received into the Fund in 1968, a handsome start towards our target of £10,000. This goal can be reached if every member gives his support by donating an amount roughly equivalent to his annual subscription. I hope that as many members as possible will use the combined Deed of Covenant and Banker's Order Form which is enclosed. This method has two distinct advantages:—

(a) It adds 70 per cent to the value of your gift. As a Registered Charity the Institution will be able to recover the Income Tax on your Covenanted gift, thereby substantially increasing its value.

(b) It spreads the load. By Deed of Covenant, you spread your gift over seven years and thus you may be able to give a larger amount than might otherwise be possible by a single lump sum.

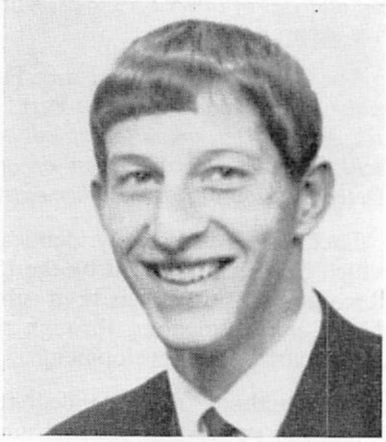
So don't wait. As I have said the Fund is to secure the Institution's future. But your donation is needed today.

Scholarship Awards in Agricultural Engineering

The Institution announces the following Scholarships to full-time students of Agricultural Engineering during 1968

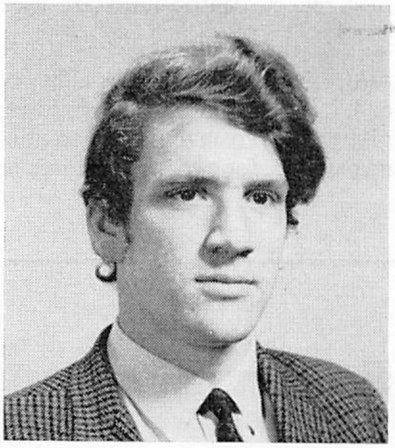
WINNER OF THE DUNLOP SCHOLARSHIP

The Dunlop Scholarship for 1968 was awarded to **Mr R. E. KIDD** aged 24, of St John's Fen End, near Wisbech, Cambridgeshire. Mr Kidd was at the County Technical College, Kings Lynn, from 1959-1963, Gloucester Technical College 1963-1964 and again with the County Technical College, Kings Lynn from 1964-1965 going on to University College, Cardiff where he gained B SC (MECH ENG) after having completed three years full time course in mechanical engineering. Mr Kidd now desires to further his studies at the University of Reading.



R. E. Kidd

SHELL-MEX & B.P. BURSARIES AWARDS



J. V. March

Mr J. V. MARCH of St Tudy, Cornwall was one of the recipients of a Shell-Mex & B.P. Bursary. Educated at Ardingly College from 1960-1965 and after spending one year practical training on a farm in Cornwall, completed a two-year course at the Searle-Hayne Agricultural College in Newton Abbot, Devon where he gained his National Diploma in Agriculture. Mr March's hobbies are rock climbing, woodwork and engine tinkering.

Mr March is now studying at the Essex Institute of Agriculture.

Mr PETER LEWIS age 22, of Basingstoke, Hampshire was educated at Queen Mary's Grammar School, Basingstoke and afterwards spent his first eighteen months working on a large farm. Mr Lewis attended The Lackham College of Agriculture from 1964-1966 and joined a large dealership in Andover for eighteen months. Mr Lewis spent a few weeks studying Italian farming in the Milan province of Northern Italy. He represented his school in football and rifle shooting. Mr Lewis is now studying at The Essex Institute of Agriculture.

P. Lewis

H. J. Holme

Mr H. J. HOLME, age 22, of Ayr, Scotland was educated at Sedbergh School, Yorkshire and then completed a two and a half year course in Agricultural Engineering at The College of Aeronautical & Automobile Engineering in Chelsea, London. Mr Holme's interests are sailing, racing dinghies and fishing and is now in his final year at The West of Scotland Agricultural College where he is studying for his National Diploma in Agriculture.

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THE REQUIREMENTS OF TRACTOR TRANSMISSIONS

by

G. J. EDWARDS, C ENG, F.I. MECH. E. *

Presented at a meeting of the Yorkshire Branch of the Institution at Leeds on 1 March, 1968

The requirements of the transmission system for an agricultural tractor are diverse and frequently conflicting. These requirements can be divided into three main groups viz. Engineering, Legal and Standardization, and Agricultural. Further sub-division within these groups can be made to show the detail requirements.

It is doubtful if any one design could ever be evolved that would satisfy all the aspects of each of these three groups and all the designs in current production are compromise solutions.

In going on to discuss in detail the various requirements only tractors of conventional configuration will be considered.

ENGINEERING REQUIREMENTS

Durability

DESIGN: When a tractor transmission is being designed basic consideration must be given at the drawing board stage to the following aspects.

Bearing Selection: Here we are considering the economy of the bearing, the capacity of the bearing and the installation of the bearing.

Is it the cheapest type of bearing, in volume production, that will perform the duty required of it?

Is its capacity rating compatible with the loads imposed under the full range of working conditions?

Does it need to be pre-loaded in any fashion?

Does it need to be a force fit on its shaft or in its housing and does this affect assembly techniques?

Is its size compatible with ease of assembly or would a bearing of greater size, at a cost penalty, provide a more simple installation and therefore cheaper assembly?

Are deflections, under normal working loads, in the components associated with the bearings within the allowable limits for these bearings?

Gear Strength: The gear elements need to be assessed from the point of view of bending and compressive strength. The type of utilization information needed to carry out the assessment of suitability of bearing capacity is needed here to assess the average level of loading in each gear and the period of time under load in relation to the expected life of the transmission.

Associated with the gears and bearings are shafts which will be subject to both bending and torsional loading. It is in the shafts that most of the deflection, that jeopardizes the lives of the bearings, occurs. Frequently assessment of shaft deflection characteristics leads to a revision of bearing requirement since a sufficiently stiff shaft imposes a choice of bearings with a capacity greater than apparently needed.

The fatigue failure of shafts can be a problem. This is particularly true of axle shafts and with this component considerable design finesse is necessary in order to achieve a sufficiently durable design.

Virtually all the tractors in volume production today utilize the transmission and rear axle casings as structural members of the tractor chassis. It is therefore necessary to consider the behaviour of these casings as load bearing members. They are usually of such complex shape that theoretical stress analysis with any real degree of accuracy is almost impossible. Nevertheless an assessment of their stiffness is possible by considering a simplified structure. An indication of their probable strength can also be gained in this fashion.

In addition to considering the isolated deflection of individual shaft assemblies within the gearbox and axle, due to internal loading, it is also necessary to assess the composite deflection characteristics of the whole design. In particular the rear axle can prove highly troublesome in respect of composite deflection. The inboard spur gear type of final reduction, for instance, is very much more difficult to design with adequate stiffness, than the outboard spur gear type.

Finally, an early assessment of the transmission environment is necessary in order to have minimum development problems with, in particular, oil seals and lubricants.

Seals adjacent to high energy/small volume brakes, such as the Girling GMPD, can prove troublesome and it is usually necessary to adopt materials, for these seals, capable of working in the higher temperature ranges. Typical specifications utilize polyacrylic or silicone elastomers.

Oils are not usually a problem in mechanical transmissions, but with the increasing interest in providing partial or total power shifting attention will have to be

* Edwards & Tyrer, Design & Development Consultants

paid to the compatibility of the lubricant specification with the clutch elements etc. in such transmissions.

Wet disc brakes need special oils containing additives to inhibit squeak, if unit pressures are high.

Hydrostatic transmissions may use sophisticated means of inhibiting scuffing between rubbing surfaces which may be the subject of attack by certain oil additives.

Greases need to be selected with care. The utilization of grease is usually confined to the lubrication of seals on initial assembly and the lubrication for life of non-accessible bearings such as the clutch spigot bearing.

Initial lubrication of seals must be carried out with a grease whose soap base will not attack the elastomer of the seal. In particular a silicone soap base grease cannot be used in association with a silicone elastomer seal.

Lubrication of a clutch spigot bearing of the anti-friction type requires a grease of sufficient consistency not to be thrown out by rotational forces. It must in addition be suitable for working at the elevated temperatures encountered in this area.

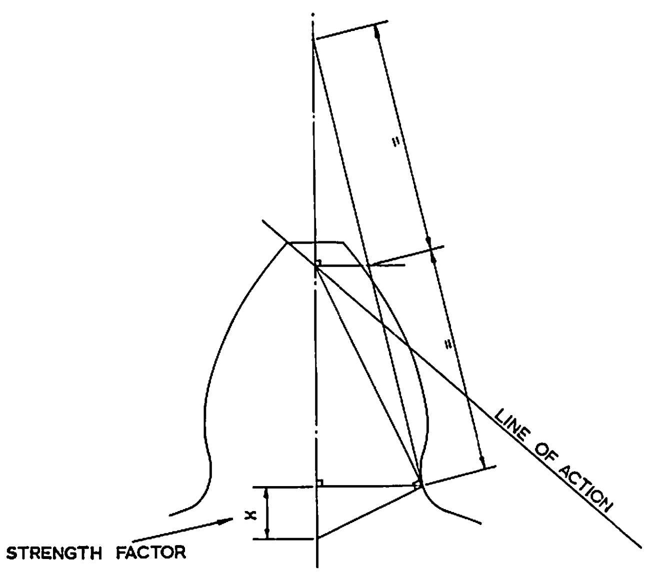

Fig. 1—Gear tooth layout for bending strength analysis

DEVELOPMENT: The state, today, of the art of tractor transmission design is such that the critical component areas are known and can be the subject of rig tests providing accelerated results comparable with field failures.

It is essential that a rig test development programme be carried out to prove the durability of critical components since the time available from the completion of the first prototype machine to the date of design freeze for production tooling may not be greater than twelve months. In that time any one machine is not likely to have completed more than 1,200 field usage hours.

Even a major design deficiency is unlikely to show up under 300 hours and subsequent redesign and retesting in the field would inevitably cause a delay in the project.

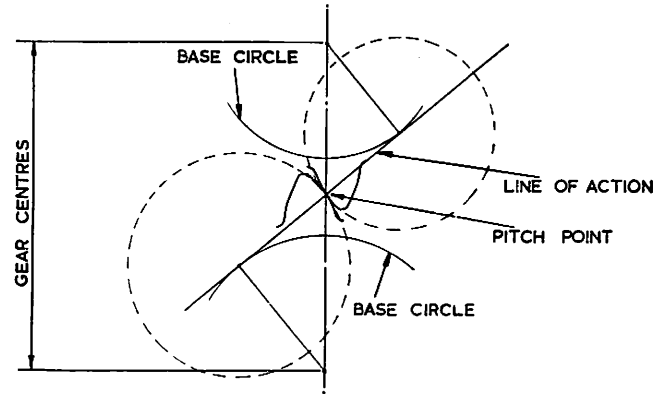

Fig. 2—Analogy of two cylinders in contact for calculation of gear tooth compressive stress

Axle testing is designed to establish the durability of the axle shaft both in torsion and in bending. The nature of the agricultural tractor is such that it is necessary for it to work across hillsides wherein the major part of the vehicle weight is on the downhill wheel and the bending moment applied to the axle shaft in this circumstance can be very high. Wide wheel settings can be used with similar results. Heavy draught loads are exerted from the implements with which the tractor will be associated resulting in high torsional loading of the axle.

The usual axle test applies (a) a cyclicly reversing torsional load to the component and (b) a bending moment at the wheel mounting flange of a rotating shaft. These two tests being carried out on separate shafts from the same manufacturing batch. With adequate attention to heat treatment and component design improvements in rig test life on this kind of component can be as high as 200/300%.

In designing for the world market it is necessary not only to consider farming practices in the U.K. but also everywhere else in the world. Under marginal traction conditions the differential lock is considered a must in the U.K. In under-developed countries with unsophisticated labour forces, tractor controls requiring finesse in operation prove a difficult training problem. The differential lock is one of these and frequently tractors are expected to travel long distances across broad acres under heavy draught conditions with one rear wheel slipping rapidly. This imposes an almost impossible working condition on the differential. Testing on the so called 4 square rig (two opposed gearbox/axle units connected together with imposed recirculatory torque) is used to evaluate the durability of the differential cross pin or spider and its associated pinions. The axle shafts on one side of the rig are locked stationary and hence with rotation of the gearbox elements 100% differential action is induced.

The 4 square rig is also used to prove the design forecast in respect to life of highly stressed gear elements. In the use of this rig one must be careful to choose levels of loading that will (a) give results in a reasonable period of time and (b) will not induce deflection characteristics

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THE REQUIREMENTS OF TRACTOR TRANSMISSIONS—*from previous page*

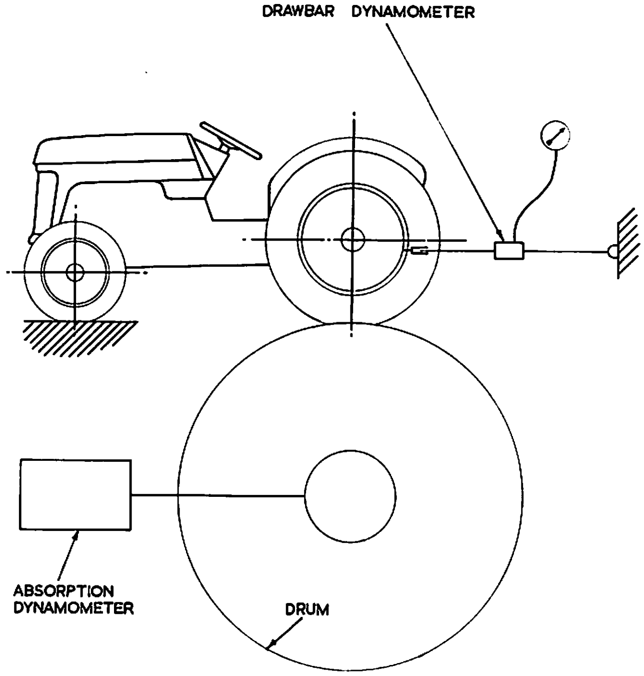

Fig. 3—Treadmill testing

within the transmission that do not pertain in field use and which unfairly jeopardize the life of the various elements.

The tests so far mentioned are all carried out under overload conditions. A stage between the overload rig test and the field endurance test is the drum or tread-mill endurance test. This is a test on a complete tractor which is mounted with the driving wheels running on drums or, in some designs of rig, tracks. The drums or tracks are connected to some form of absoption dynamometer and the test tractor is hitched to a rigid anchor usually via the drawbar. The test tractor then drives the rig via the drums or tracks against a variable resistance imposed by the dynamometer. Measurement of the drawbar pull generated by the test tractor can be achieved by a drawbar dynamometer. Uusually, the test programme is formulated so that the equivalent distance covered by the tractor is approximately 5,000 miles during a period of 1,000 hours.

The larger proportion of the hours of the test are carried out in the ploughing gears. In general the level of engine power utilization should increase with speed and the overall average utilization will vary with the size of the tractor. The point being that a smaller low powered tractor in service will always be used harder than a larger high powered tractor. An adequate design should prove trouble-free during a 1,000 hour test on a drum-mill.

The transmission casing components that go to make up the chassis of the tractor must be capable of withstanding cyclic loading, applied at the rear wheel mounting flange, vertically up and down, horizontally fore and aft, and torsionally. Rigs are constructed to provide this type of test. In order to simulate rearing conditions and high speed passage over hard rutted ground the bump test is formulated. The front of the tractor is lifted about the rear axle centre and then dropped (a) on to the front wheel tyres, (b) on to one tyre with the front axle baulked from swinging and (c) on to anvils. Each of these tests is carried out for several thousands of cycles.

Associated with the physical strength tests of the chassis components are the stress analysis tests. Perhaps the most useful of these is the brittle lacquer technique. In this type of test components are loaded statically in a similar fashion to that expected in service after spraying under controlled conditions with a lacquer which upon drying and curing becomes consistently brittle and which upon straining will crack. The intensity of cracking is indicative of the intensity of strain and hence stress and the direction of cracking will lie at a right angle to the plane of principle stress. Use of this technique at an early stage leads to extremely useful design improvements at little cost.

The unusual attitudes in which the agricultural tractor is called upon to perform necessitates careful evaluation of the lubrication characteristics in these attitudes. A sectioned gearbox and axle assembly mounted on a tilting table is used for this purpose.

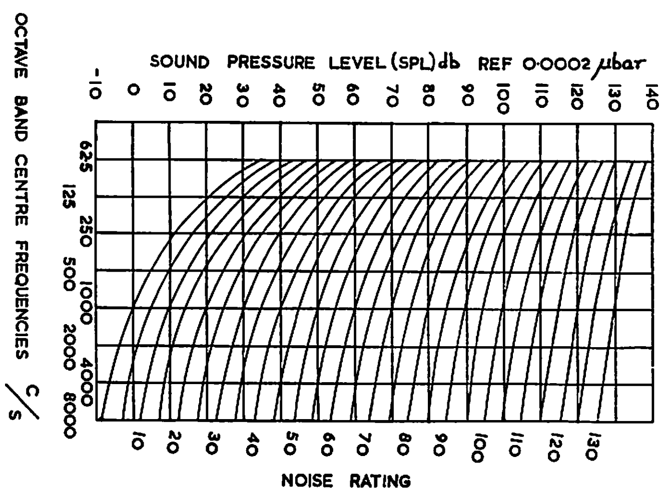

Fig. 4—Equal annoyance curves

Field evaluation, in addition to proving the adequacy of the complete vehicle as an agricultural machine, has a great use in showing up random unexpected failures for which no rig test has been formulated and which normally occur in areas not considered to be critical during the early design considerations. An important function of field evaluation is the assessment of environmental conditions to prove the rightness of design decisions in respect to those aspects.

MAN/MACHINE RELATIONSHIP

NOISE: The demand today is for tractors, to use a word coined by Mr T. C. D. Manby of the NIAE, 'of increased "comfenience" ', meaning comfort and convenience. Paramount among the criticized aspects of current tractors is the excess of noise.

Two aspects of noise emission concern the transmission engineer: harmful noise and annoying noise.

The study of harmful noise demands an understanding of the measurement of noise levels. Many units have been devised for the comparison of loudness and annoyance of sounds. The International Standards Organization have adopted for comparison of annoyance a series of noise rating curves which are numbered by their sound pressure level (SPL) at 1,000 c/s. The Medical Profession defines NR85 as the 'Damage Risk Criteria'. Exposure to sound pressure levels above this curve on a continuous basis can result in hearing loss. The nature of noise is such that if a high sound pressure level is established at a particular discreet frequency then this will dominate the sound picture. High sound pressure levels are generated by the diesel engine and in general they over-shadow the noise emitted from a mechanical transmission.

This is not necessarily true of hydrostatic transmissions and particular attention to casing design is necessary if the efforts of the hydraulic transmission manufacturers in reducing the noise emission on their units is not to be negated by the transmission engineer installing the unit in an efficient sound box.

Annoying noise can easily become a problem in mechanical tractors. Examples of annoying noise are: the whine of gearbox elements with profile and lead errors, the cyclic hum of a bowed crown wheel, the rumble of a heavily loaded final reduction gear set with inadequate profile and lead correction to cater for deflection, the rattle of a slack differential under high speed transient torque conditions.

With the expected reduction in sound pressure levels emitted from the engine the significance of annoying noise will increase and greater attention to the reduction of this type of noise will become necessary.

Physical Efforts: Improvements in design and manufacturing techniques are permitting increased powers to be transmitted through smaller packages. In attempting to contain the effects of greater deflections due to higher loads stronger retention springs are likely to be chosen for gear change levers.

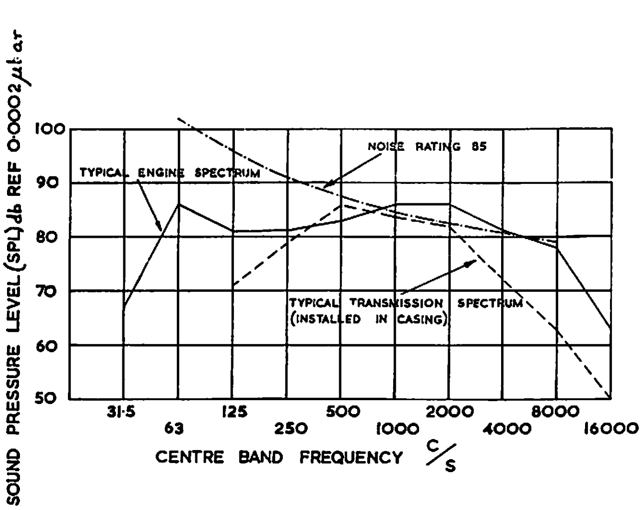

Fig. 5—Octave band spectra

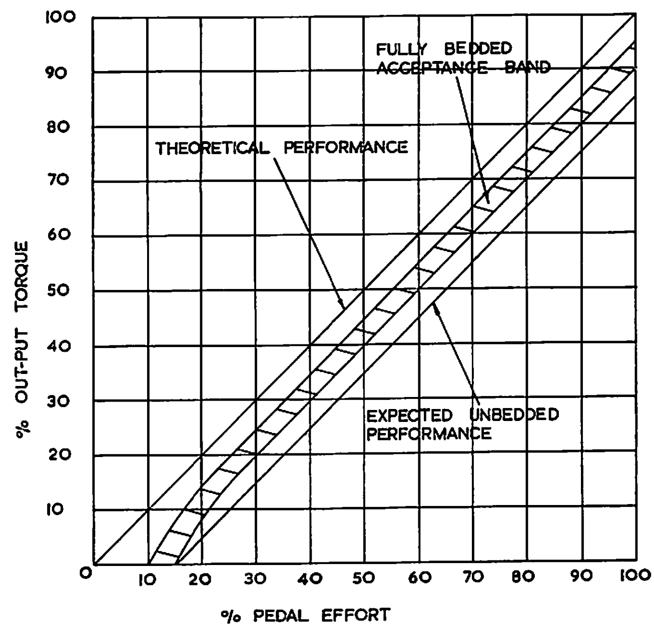

Fig. 6—Typical brake performance

For a well positioned lever the optimum effort required at the gear lever knob to originate a gear change is between 6 and 8 lb. This is the force required to lift the detent ball out of its notch.

Limitations of space usually preclude an increase of clutch size with increased engine power. Hence a greater clamp load is required in the existing clutch. The pedal effort to actuate the clutch should be in the range of 30 to 35 lbs.

The efforts required to actuate the tractor braking system vary with the tractor weight. The ratio of weights of a bare tractor and a tractor and laden trailer combination can be as high as 3:1. The foot does not apply light loads easily, particularly loads less than the normal reaction to the weight of the leg. If it is assumed that the normal reactive force to the weight of the leg is 10 lb and that this provides a deceleration of 2 ft/sec^2 on a bare tractor, to decelerate such a tractor at 10 ft/sec would require a pedal effort of 50 lb. To provide this deceleration on a tractor and laden trailer combination would require a pedal effort of 150 lb.

Servo-assisted systems have not as yet found favour on the agricultural tractor. It is possible that they may do so in the future.

Position: The position of the controls for actuation of the transmission is dependent upon the overall chassis design in respect to the seating position and its relation to the other vehicle controls. The target is to ensure that there is as much space as possible left available for access onto the vehicle and that once the driver is in position the controls fall easily to hand. They should be sited in such a fashion that they are not easily caught up in the loose and bulky clothing that is likely to be worn by the driver in inclement weather. The gating for the gear change levers on mechanical transmissions should be simple and the changes arranged in a progressive fashion.

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THE REQUIREMENTS OF TRACTOR TRANSMISSIONS—*from previous page*

SAFETY

The general subject of safety is covered by certain legal requirements which will be dealt with later but there are two aspects which are more correctly considered under the heading of the engineering requirements.

GUARDING: No control lever should be sited in such a position that it is likely to be kicked, trodden on or pushed into or out of engagement by any reasonable movement or action on the part of the driver. Nor should it be likely that any clothing that the driver might be wearing will catch on or become attached to any lever.

Safety devices precluding engine start unless the transmission is in neutral are highly desirable.

CENTRE OF GRAVITY: The transmission engineer and the chassis engineer together are conscious of the need to design a vehicle with a centre of gravity sufficiently low for the vehicle to be safe in the unusual attitudes in which it is obliged to work.

On the other hand there is the demand for a sufficiently high under belly height to provide adequate crop clearance.

ECONOMY

DESIGNING FOR VOLUME PRODUCTION: Conventional configurations of tractor rely universally on the fore and aft engine, driving in the majority of cases only the two rear wheels. Therefore in a mechanical transmission tractor or in an hydraulic transmission tractor utilizing a gearbox replacement unit there is a need for a bevel gear set to change the direction of drive.

Whilst large crown wheels can be cut by machines utilizing high volume production techniques these machines are very expensive and problems of heat treatment multiply rapidly with increase in crown wheel size. Purchase of this type of plant can only be justified for long production runs.

Any manufacturer intending to produce a range of tractors would wish to utilize his plant fully. The double reduction axle becomes attractive from the plant economy point of view when considering machines such as those required to produce the bevel gears. The same machinery can be used to produce components appropriate to a minimum horse power tractor with a single reduction axle and a higher horse power tractor with a double reduction axle since the torque level, at the crown wheel, will be of the same order on the two machines.

The ultimate in axle shaft durability is achieved by using an induction heating technique of surface hardening; as with the machinery required for bevel gear production. This type of equipment can only be amortised over a large volume of components. Any manufacturer considering only small volume production is faced with extremely difficult decisions to resolve in that the requirements of economy of production are in conflict with the requirements of adequate durability. The rapid increase in cost per horse power of tractors in the over 65 hp classes is due in large part to this factor.

ECONOMY OF STRENGTH: Tractor selling prices are highly competitive and no manufacturer whose prices are greatly in excess of the average will sell his product in volume.

The transmission engineer is faced with the problem of judging the optimum level of utilization and designing for optimum life at that level.

The user whose needs are in excess of the optimum utilization is likely therefore to be faced with reduced component lives. This aspect poses one of the most demanding challenges on the transmission engineer since if he can evolve a stronger design at no greater cost then the product service record in the difficult areas will be improved and sales will increase.

LEGAL AND STANDARDIZATION REQUIREMENTS

As with the need to consider farming practices throughout the world in respect of their influence on durability so there is the need to consider the legal and standardization requirements of the various countries to which the vehicle will be exported. The requirements set by the legislatures in those countries must be met and as closely as possible the requirement of the various standards institutions should also be met.

Appendixes 1 & 2 summarise the legal requirements in respect of road speeds and brake design and performance.

The requirements of standards institutions, in so far as they affect the transmission, are concerned primarily with (a) the power take off (engine driven) and guard, (b) the ground speed drive power take off, (c) the belt pulley and (d) the relative positions of tractor driving controls.

British Standard Specification BS.1495-1964 makes recommendations in respect to those items which in general are followed.

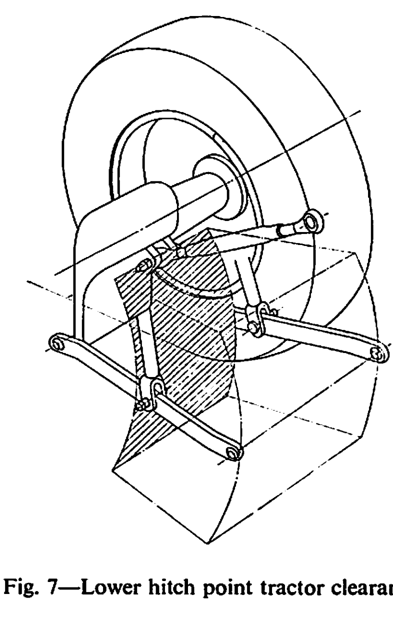

Fig. 7—Lower hitch point tractor clearance

AGRICULTURAL REQUIREMENTS

The use of agricultural tractors can be split into the following classifications:

1. Pulling ground engaging implements: ploughs, cultivators etc.
2. Pulling and driving through the p.t.o. shaft various implements: mowers, forage harvesters, balers, combines, rotavators etc.
3. Transport work.
4. Stationary work, driving threshing machines, pumps, compressors etc.
5. Serving as motive power for a special group of mounted implements: loaders, rakes, small bulldozers etc.
6. Forming the base of special machines built around the tractor: mounted combines, some road making machines, trench diggers etc.

The versatility of performance demanded by the diverse duties the tractor is called upon to perform require that the full engine power be available as nearly as possible throughout the full working speed range of the vehicle.

SPEED RANGE

The maximum speed as indicated earlier is influenced strongly by the demands of the various legal requirements of the countries to which the tractor is likely to be exported.

Vehicle utilization at the higher speeds permitted by some countries is confined to transport woık. In order to achieve the greatest market penetration the normal maximum speed of the vehicle is usually chosen at around 15 mile/h. For those countries which limit the maximum speed at a lower level than this top gear can be blocked out.

The minimum speed should be approximately 1 mile/h certainly not more than 1.5 mile/h.

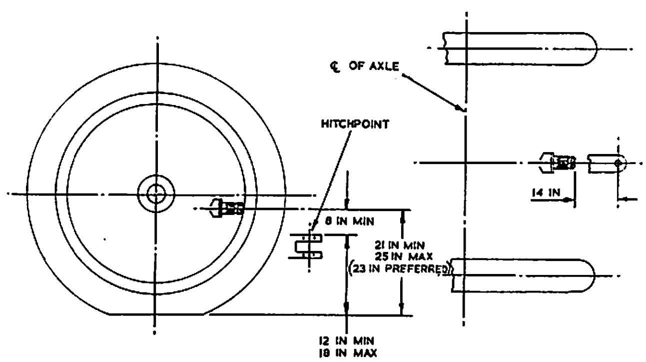

Fig. 8—Lower hitch point tractor clearance

The wider the spread between the minimum and maximum speeds the greater the ratio coverage needed in the gearbox. A tractor/implement combination may reasonably be expected to work effectively at plus or minus 20% of the ideal speed. It follows therefore that the factor between intermediate ratios in a mechanical gearbox should not be greater than 1.4. Some power take off driven equipment is only happy when being driven within a fairly narrow speed band surrounding the mean. With this type of implement full advantage of the available engine power can only be ensured in a vehicle utilizing an infinitely variable drive.

For a mechanical gearbox, with a constant geometric factor between ratios, it can be shown that:

$$\frac{S}{s} = f^{(N-1)}$$

Where S = Maximum Speed

s = Minimum Speed

f = Geometric Factor

N = Number of Ratios

This expression can be written:

$$S = \text{antilog.}(\log.s + (N\text{-}1)\log.f)$$ Legal, Marketing and and Engineering Limitation

$$s = \text{antilog.}(\log.S(N\text{-}1) - \log.f)$$ Agricultural and Engineering Limitation

$$f = \text{antilog.}\frac{(\log.S - \text{Log}.s)}{(N\text{-}1)}$$ Agricultural Limitation

$$N = \frac{(\log.S - \text{Log}.s)}{\log.f} + 1$$ Engineering and Ergonomic Limitation

For a vehicle with a maximum speed of 15 mile/h, a minimum speed of 1 mile/h and constant geometric factor of 1.4 the number of ratios required is 9. A design with 8 speeds would probably be adquate and 10 speeds would apparently be better, giving greater overlap.

Economy of design demands that such a plurality of speeds be provided by using a 'range' type of configuration. There are two fundamental approaches (a) use a 'splitter' range wherein each ratio has provided a high and a low range to be associated with it and (b) use a progressive range system wherein the ratios in each range follow in sequence the ratios in its adjacent range.

Scheme (a) is easier to incorporate when updating an existing design but must be non-preferred since it involves a double change at every other ratio.

Scheme (b) is much better. With 8 or 10 speeds in two progressive ranges the double change in a gearbox covering 1 to 15 mile/h would lie between 3.2 and 4.7, and 3.3 and 4.5 mile/h respectively. These speeds are at the lower end of the ploughing speed band and it is undesirable that a double change should be in this aıea.

To cover the full speed range a gearbox with 9 speeds in three progressive ranges will need two double changes but these will lie between 1.96 and 2.76, and 5.4 and 7.6. This fits in very well with the concept of three woıking ranges for the tractor (a) a creeper range for: mole draining, potato harvesting, steerage hoeing etc., (b) a field range for: ridging, forage harvesting, ploughing etc. and (c) a road range for haulage work.

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THE REQUIREMENTS OF TRACTOR TRANSMISSIONS—*from previous page*

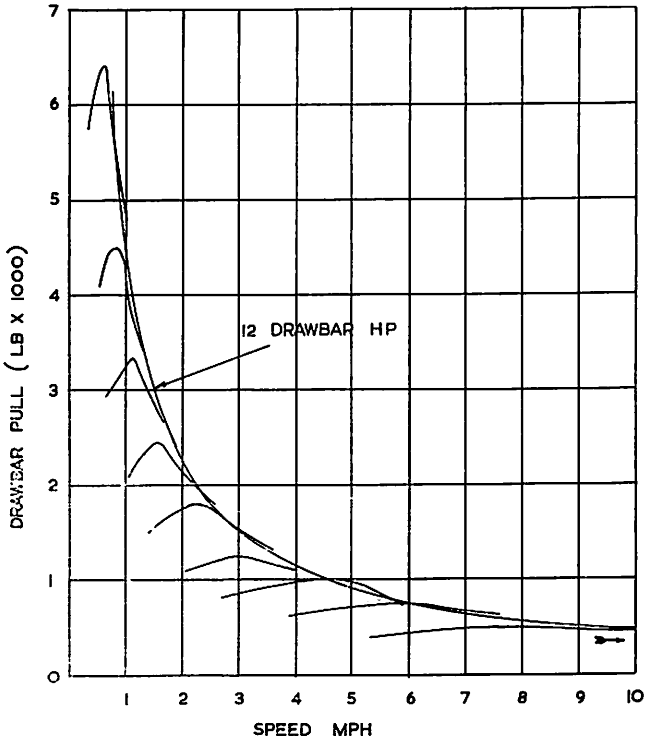

Fig. 9—Power take off and Drawbar high locations (540 rev/min)

A three range system offers the advantage that by placing the reverse idler in the range side of the gearbox rather than in the ratio selection side a much more useful set of reverse gears can be achieved.

A reverse idler sited in the ratio selection side of the gearbox achieves reverse ratios whose speeds would lie somewhere in the speed bands covered by the creeper, field and road ranges. The creeper reverse speed would be too slow to be useful, the field reverse would be the one normally used and the road reverse would be too fast for safety.

By placing the reverse idler in the range side of the gearbox the reverse speeds can be made identical to, or slightly in excess of, or less than, the forward speeds in the field range, thus providing three useful reverse speeds.

RATIO CHANGING

The sliding gear type of ratio change for the mechanical gearbox is still in common usage but it must be considered today as obsolete. Efforts required to effect gear changes with this type of design tend to be high and changes on the move, particularly if the factor between gear changes is not ideal, require a high level of skill.

Much more preferable is the sliding collar constant mesh gearbox. Given sufficient design finesse, in the changing elements, 'sweet' changing on the move can be achieved with little skill.

Synchro-mesh types of gear change, either of the constant load or baulk ring type, have certain attractions but the size of the gear elements and hence their inertia tend to make the synchro-mesh components very large. In general synchro-mesh can only be justified between the higher ratio pairs in the road range. This however does not fit in very well with the progressive range type of design.

Probably the most significant advance in ratio changing in recent years has been the introduction of the power shift 'splitter'. In this design a conventional mechanical gearbox is associated with a set ot gears which provide a ratio inciease or decrease wherein the change can be effected by powered means.

One fundamental problem is inherent in this type of design. Tractor operational speeds being low and the pulls high (with the exception of road work) unless the torque transmission from the engine to the rear wheels is maintained during the change sequence the tractor will momentarily stop. This can easily induce wheel slip and negate the advantage of having power shifting.

One way of effecting continuity of torque is to arrange for one of the ratios to be transmitted through the gearbox by means of an overrun clutch. This design is adopted in the Massey Ferguosn 'Multi-Power'. Whilst drive is being transmitted through the overrun clutch there is the disadvantage of loss of engine braking which is not good from the safety aspect.

The International Harvester 'Speed-Amlifier' sets out to achieve the same ends but by use of an epicyclic gear train rather than a lay shaft design. In this design also the drive in one circumstance is transmitted through an overrun clutch, the outer race of which forms the inner race of a further overrun clutch whose outer race is in turn associated with the p.t.o. drive shaft, via suitable gearing, so that engine braking is still achieved.

Partial power shifting is provided in the International Harvester 'Agriomatic' transmission. This is a design of considerable ingenuity: its most attractive feature being that it is possible to achieve not only a powered change between two gears in the forward direction but also a powered change from forward to reverse. In this design synchro-mesh is provided in the ratio side of the gearbox.

Gearboxes giving full power shifting between all gears have been produced for agricultural tractors and perhaps the best known of these is the Ford Select-O-Speed. The gearbox consists of three epicyclic gear trains compounded together to provide a total of 10 forward speeds and two reverse speeds. Control of ratio changing is effected by brake bands and multi-plate clutches.

Smooth gear changing without loss of continuity of power is difficult in designs of this kind and cost and reduced efficiency can be a problem.

The ultimate in providing ratio change coverage is achieved with the hydrostatic transmission. Only two tractors are currently being produced utilizing transmissions of this type: Eicher in Germany and International Harvester in America. The Eicher tractor utilizes a straight gearbox replacement hydrostatic unit and the International Harvester a gearbox replacement unit together with high/low range mechanical gear change.

Pre-supposing that the versatility of the hydrostatic drive will eventually lead to its general adoption then user acceptance will be influenced by the adequacy or not of the control system. Tractor drivers are accustomed to mechanical gearboxes with a conventional clutch mechanism. Use of the clutch in conjunction with the vehicle brakes allows delicate manoeuvring with ease. The immediate vehicle response in terms of change of speed with change of ratio with an hydrostatic transmission can be very disconcerting. The response rate of servo controls can be damped but this can lead to problems of engine stalling under conditions of rapid build up of transmission loading. Possibly some form of variable response control may be included in future designs.

IMPLEMENT ACCESS AND ATTACHMENT

In addition to meeting the standards requirements in respect of position of the rear p.t.o. in relation to the lower link ends it is necessary to consider the effect the position of the lower link ends on the stability of the tractor/implement combination. The position of the p.t.o. shaft should not be so far to the rear of the rear axle centre line that the front end weight of the tractor is jeopardized when carrying implements in the transport position.

If a centre p.t.o. should be fitted then it cannot significantly jeopardize crop clearance at the centre of the tractor. Moreover, the gearbox profile in this area must provide sufficient clearance for attachment of the most likely implement to that associated with this p.t.o. viz the mid-mounted mower.

PROVISION OF HYDRAULIC POWER

Existing designs of tractor tend to have numerous individual pumps to provide hydraulic power for power-assisted steering, for providing the power gear change function, for the tractor hydraulics and for external services.

Future transmission will have to be designed so that these functions can be centralized in one area and one would expect that no longer will it be acceptable for tractor hydraulics to be sensitive to the p.t.o. clutch.

P.T.O. CLUTCH

In common usage is the dual clutch which provides separate driven plates and springs in a combined cover assembly for the traction and p.t.o. function. The traction clutch is conventionally foot operated and the p.t.o. clutch may be foot operated by increased pressure or independently operated by a hand lever.

The requirement expressed above for fully live hydraulics independent of the p.t.o. clutch imposes a limitation on the siting of the hydraulic pumps. If designs continue to be evolved around the currently used dual clutches the hydraulic pumps, in order to be engine sensitive, will need to be sited at the front of the engine. This concept results in relatively long suction lines if the transmission fluid is used as the hydraulic media.

Centrally disposed pumps associated with the transmission preclude the use of the dual clutch and for this reason the hydraulically operated multi-plate p.t.o. clutch is coming into vogue. Considerable finesse in design is necessary here in order to provide an inching characteristic with this type of clutch.

Another reason for the increasing interest in the hydraulically operated p.t.o. clutch is relative inadequacy of the dual traction/p.t.o. clutch particularly at higher engine powers.

The dual clutch has given good service for a number of years but it has always been a little suspect under conditions of arduous operation of the traction clutch, in particular front end loading.

Greater durability can be ensured with a single function clutch.

UNKNOWN FACTORS

This is the most nebulous of the agricultral requirements of a tractor transmission. The manifold and still broadening applications of tractors demand that the transmission system be as versatile as possible.

Two speed power take-offs are coming into vogue and as they are taken advantage of by the implement manufacturers they are likely to become a must in a competitive vehicle. The popularity of ground speed sensitive power take offs similarly is likely to increase.

The centre power take-off engine and/or ground speed sensitive must be considered for future designs.

ARE THE REQUIREMENTS BEING MET?

The answer to this question is explicit in the broad picture of these requirements that has been set out in the first part of the paper.

The majority of tractors currently in production do not meet all the requirements. Some meet them to a greater extent than others, the more recent the design the more nearly the majority of requirements are likely to be met.

The need to amortise plant provided to produce existing designs before embarking upon major design changes precludes the frequent introduction of new designs.

Fashion plays little part in the selling of tractors. Durability, reliability and adequacy of function are far more important. Durability and reliability on the whole are likely to improve the longer a model remains in production. However, marketing demand for increased power can adversely effect these factors.

Eventually it will be lack of adequacy of function that will enforce a model change.

User demand is conditioned by the products currently available, any major change is only likely to stem from a break through in tractor concepts.

FUTURE TRENDS

Clutches

The conventional dual clutch is likely to remain for the 35 to 60 hp class. Above 60 hp the automotive type clutch will probably be used with hydraulically operated multi-plate clutches for p.t.o. operation.

Twin plate traction clutches and belleville spring clutches to reduce pedal efforts should not be discounted.

Please turn to next page

THE REQUIREMENTS OF TRACTOR TRANSMISSIONS—*from previous page*

Possibly we shall see an interest in oil cooled clutches but this is likely only for specialist operations such as continuous front end loading.

Mechanical Transmissions

The three range system is expected to become popular, probably with 9 forward speeds but perhaps 12 speeds in three ranges of four.

Synchro-mesh in the higher speed gears might be demanded perhaps as an optional extra. Certainly the sliding collar type of change, at least, will become a must. The use of helical gears for greater durability and quietness will increase.

Some form of power shift 'splitter' will become commonplace as an optional extra.

The advance of full power shifting gearboxes will depend upon the penetration made by hydrostatic transmissions.

Overall noise values will be expected to reduce.

Hydrostatic Transmissions

Significant penetration into the market by this system is likely to originate with the gearbox replacement unit. However, it is not expected that this will displace the mechanical gearbox from its dominant position.

A major change in tractor configurations, however, may lead to almost complete adoption of this type of drive.

Brakes

Sealed braking systems will become universal. It will be interesting to watch the development of the oil immersed brake. Powered systems are likely in the higher power class.

Hydraulic operation of mechanical brakes which provide balanced braking on demand is likely to become popular.

Acknowledgements

The author wishes to thank the Directors of Tractor Research for their permission to publish this paper. He thanks Professor Ewen M'Ewen for his permission to reproduce the information shown in the appendixes which first appeared in Professor M'Ewen's paper 'Tractors for the World Market'.

The invaluable assistance given by The British Motor Corporation; Ford Motor Company; Girling Ltd; International Harvester Co; Lucas Industrial Ltd and Massey Ferguson Ltd in respect of information and visual aids is gratefully acknowledged.

Finally the opinions expressed are those of the author and not necessarily those of his employers.

APPENDIX 1

MAXIMUM SPEED LIMIT FOR TRACTORS

Current Regulations

Present speed limits are as follows:

1. United Kingdom: 20 mile/h for tractors on own or with mounted implements; 5 mile/h if drawing two trailers; 5 mile/h if tractor is not fitted with resilient tyres.
2. France: 16.8 mile/h (27 kph).
3. Germany: 12.4 mile/h (20 kph). Depending on driving license, insurance, and brakes, it is possible to exceed 20 kph.
4. Italy: 24.8 mile/h (40 kph).
5. Switzerland: 12.4 mile/h (20 kph). This is subject to a plus 10% tolerance to allow for governor runout.
6. Austria: Up to 37.2 mile/h (60 kph), depending on class of tractor.
7. Holland: 14.9 mile/h (24 kph).

Cema Proposal

For agricultural tractors on their own or with a side-mounted mower the maximum speed limit will be 25 kph (15.5 mile/h). This maximum speed limit is calculated on the nominal engine speed, the gear ratio between engine and back axle, and the effective radius of the rear tyres in accordance with the maximum permissible allowable weight on the back axle. The speed limit for agricultural tractors with detachable mounted or semi-trailed implements or trailers with a constructional speed limit of 20 kph (12.4 mile/h) prescribed should be at the maximum speed at which the tractor may be used. An express condition for the adoption of this speed limit is that all exemptions at present in force in countries in which the speed limit is below 25 kph (15.5 mile/h) should be maintained.

When the maximum speed is checked by practical tests, a tolerance of +10% must be allowed for engine governor runout; otherwise the manufacturer of agricultural tractors might base his calaculations on a speed of 22.5 kph (14 mile/h) on the road instead of 26 kph (15.5 mile/h). A speed of 27.5 kph (17.1 mile/h) ascertained by speed measurement on the road should therefore be permissible.

APPENDIX 2

BRAKES

Current Regulations

Brake regulations in the various countries are listed below:

1. *United Kingdom*
   (a) Legal requirements for industrial tractors are that they must be equipped with two separate and efficient braking systems, having two separate means of operation, and working directly on two wheels, which will bring the vehicle to rest in a reasonable distance under the most adverse conditions.

(b) The means of operation must be such that application of one system shall not affect or operate the other.

(c) At least one means of operation must be capable of causing the brakes to be applied directly to at least two wheels and not through the transmission gear.

(d) Land tractors need have only one braking system, working on two wheels, provided the operation lever is capable of being locked on for both wheels.

(e) Hydrostatic transmissions that could have a braking effect on the road wheels have not been recognized by the Ministry of Transport.

(f) Any system embodying either a vacuum or pressure reservoir must be provided with a warning device to indicate any failure of the system and must be readily visible to the driver when he is in the driving seat.

(g) No braking system shall be rendered ineffective by the non-rotation of the engine.

2. *France*

(a) One single braking system, provided it is constructed to be reliable, is satisfactory.

(b) The operating lever must be in such a position that the driver can operate from the driving seat and without abandoning his hold on the steering wheel.

(c) The brakes must act equally on wheels on either side of the tractor.

(d) The efficiency of the brakes must be such that they are capable of stopping the tractor from a speed of 20 kph (12.4 mile/h) within a distance of 10 m (32 ft 9¾ in.).

3. *Germany*

(a) Two independent braking systems are required, one of which must be capable of being locked on for parking purposes.

(b) The average minimum retardation of the tractor is to be 1.5 m/sec^2 (4.92 ft/sec^2). One brake must give 2.5 m/sec^2 (8.2 ft/sec^2) and with the other 1.5 m/sec^2 (4.92 ft/sec^2). Retardation is also related to pedal load and tyre loading.

(c) If independent brakes are fitted, then the pedals must be lockable for use as a master pedal for road use.

4. *Italy*

(a) A tractor fitted with either pressure or vacuum operation must have either a visual or acoustic warning device to commence when the reserve has gone down to 35% of the minimum rating.

(b) For power operated systems, it is essential that brake efficiency not be lost completely should the engine stop.

(c) For hydraulically operated systems, hydraulic tank must be readily accessible for filling, and if not fitted with level gauge, it must be situated for easy inspection of fluid level.

(d) A service brake and emergency brake can be combined and have the same control and parts of the transmission in common, provided braking on at least one axle is assured in the case of one of the common parts breaking. The service brake and emergency brake must act on the wheels of one axle, though not necessarily the same axle.

(e) Braking efficiency with the service brake must satisfy

$$S < 0.15V + \frac{V^2}{130}$$

where: S= Distance to stop (metres)
V= Speed (kph)

and this result must be obtained by not exerting a force on the operating control in excess of 60 Kgs.

(f) The emergency braking device must be capable of stopping within twice the maximum prescribed for the service brake.

(g) The parking brake must be capable of holding the tractor steady, either uphill or downhill on a gradient of at least 16%.

5. *Switzerland*

(a) Tractors must be equipped with either two independent brakes or one brake with two independent operating devices.

(b) Each brake must be operative should the other fail.

(c) One brake must be lockable and capable of holding the tractor on a gradient of at least 1 in 6.6.

Cema Proposal

The braking system for tractors with a speed up to 25 kph (15.5 mile/h) should consist of at least one brake acting on the driven axle with two independent controls, one of which must be capable of being locked. The hand brake may act on the same transmission components. The braking system of a tractor should be constructed in such a way that the tractor with a permissible total weight can pull up within a distance of 10 m (32 ft 0 ins.) on a flat level surface, having a coefficient of friction of 0.7 from a speed of 20 kph (12.4 mile/h).

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Approved by Council at its meeting 10 October 1968

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was typical of a well attended branch meeting in any area in the United Kingdom. However, Northern Ireland was without a branch as yet and a minimum membership of 50 would be needed to form a viable branch.

Whilst financing a branch was a problem especially in the case of Northern Ireland where some of the speakers would have to travel from across the water, it was felt that support from within Northern Ireland might eventually be forthcoming in the form of meetings endowed by various organisations or large firms.

In concluding the meeting the Chairman, Mr D. C. McRae invited new membership and stressed that if all present joined the Institution of Agricultural Engineers, a branch would be an immediate practical proposition. Anyone interested in joining the Institution or obtaining more information about it should contact Mr McRae at 120 Westland Road South, Cookstown. (Telephone Cookstown 3443 after 6.0 p.m.)

SCOTTISH BRANCH

Scottish Branch are pleased to announce details of their 1969 Conference which will be held in the Royal Highland Society Showground, Ingliston on the 27th February 1969 the subject being 'Crop Protection'.

Four papers will be presented:

Paper I—'First Principles' by Dr Martin of The West of Scotland College of Agriculture, Glasgow.

Papers II & III (finalized titles not yet announced) will cover application techniques and mechanization and will be presented by R. C. Amsden of Chesterford Park Research Station and J. B. Byass, NIAE, Silsoe respectively.

The final paper 'Crop Spraying—an economic necessity' will be presented by R. F. Norman, Development Director of Fisons Limited, Cambridge Division.

The better known manufacturing names in the spraying world have agreed to be represented in the static display of equipment held during the day. The finalized programme and tickets (concession price to members 30/- including lunch) will be available early in the New Year from the Hon. Secretary, Scottish Branch, A. Hardie, The Edinburgh School of Agriculture, West Mains Road, Edinburgh 9.

Though activities of the Scottish Branch have been somewhat curtailed an evening meeting on the subject of 'effluent disposal' was held in the Station Hotel, Perth on the 7th November.

There were two main speakers J. A. Rangely of the Tay River Purification Board and Dr Baynes of The West of Scotland College of Agriculture; C. J. Swan, Scottish Branch Chairman being in the chair.

D. S. Soutar and Seton Baxter of the Farms Buildings Investigation Unit led the contributions from the floor while Jim Watson, Muir of Pert Farms lent support with down to earth practical experience.

EAST ANGLIAN

Over 200 engineers and farmers attended a conference in Norwich on the 21st November, where they heard speakers from home and abroad discuss future trends in root harvesting.

Mr J. H. Cock, Chairman of the meeting, said he thought it was an advantage that the conference had been postponed from last year as there had been great developments during the year. Much experience had been gained in one of the worst years in arable farming.

There would be more potatoes processed in the future, said Mr C. de B. Codrington, Machinery Officer of the Potato Marketing Board. We ate about 200 lb. of potatoes each a year and he forecast that about 25% of them would be processed by 1972.

He stressed the need for greater care in handling and grading and thought that central grading stores would be best. An efficient electronic grader was required as there was too much reliance placed on unskilled women at present; their eyesight is not even tested.

Mr W. J. Whitsed of Root Harvesters Ltd. said that there would be a 50-100% increase in potato harvester output if there were a nation-wide change from 28 to 36 inch rows. Assuming the plant population remained the same, the travelling distance for an acre would be reduced from 6,000 yards to 4,840 yards and the quantity of soil to handle be reduced from 300 to 240 tons per acre. There would be much more room for tractor tyres and thus less compaction at the sides of the rows.

On the growing of sugar beet, Mr A. C. Owers, Director of the Norfolk Agricultural Station, said that plant breeders could produce a round beet like a red beet or mangold, with the same sugar content as our present deep-rooted beet; they would require much less work to lift but could not be topped with conventional toppers, which require the beet to be held rigidly. An alternative to mechanical topping might be a chemical defoliant followed by a sprout suppressant to inhibit leaf growth in the clamp.

Comparing the systems of harvesting sugar beet in different European countries, Mr J. Jorritsma, head of the Dutch Sugar Beet Institute, said that topping was not so critical on the Continent as it was in Britain, nor were harvesting conditions so bad or so long. He thought the trend was to either self-propelled tankers of up to three rows or separate stage five or six row machines. It was important to have an excess capacity in harvesters to avoid damage to soil structure.

Mr J. B. Holt of the NIAE thought that the farm power unit of the future would be split into three different units, all built from standard parts. There would be a powerful pulling unit for heavy cultivation, self-propelled machines for planting and harvesting all crops and self-propelled transport units.

Mr F. Oldfield of the Raynham Farm Co. Ltd. said he had had a year's experience of a three stage system and he thought it was the most suitable system for them; it enabled the beet lifting to be fitted in with all the other autumn work. Smaller farmers could make use of this system by pooling permits as was done at present for haulage.

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Abbreviations and Symbols used in the Journal

a	year	l	litre
A or amp	ampere	lb	pound
ac	acre	lm	lumen
a.c.	alternating current	m	metre
atm	atmosphere	max.	maximum (adjective)
b.h.p.	brake horse-power	m.c.	moisture content
bu	bushel	m.e.p.	mean effective pressure
Btu	British Thermal Unit	mile/h	miles per hour
cal	calorie	mill.	million
c.g.	centre of gravity	min	minute
C.G.S.	centimetre gramme second	min.	minimum (adjective)
cm	centimetre	o.d.	outside diameter
c/s	cycles per second	o.h.v.	overhead valve
cwt	hundredweight	oz	ounce
d	day	Ω	ohm
dB	decibel	pt	pint
D.B.	drawbar	p.t.o.	power take-off
d.c.	direct current	qt	quart
°C, °F, °R	degree Celsius, Fahrenheit, Rankine	r	röntgen
deg	degree (temperature interval)	r.h.	relative humidity
dia	diameter	rev	revolutions
doz	dozen	s	second
e.m.f.	electromotive force	s.v.	side valve
ft	foot	S.W.G.	standard wire gauge
ft^2	square foot (similarly for centimetre etc.)	t	ton
ft lb	foot-pound	V	volt
G.	gauge	v.m.d.	volume mean diameter
g	gramme	W	watt
gal	gallon	W.G.	water gauge
gr	grain	wt	weight
h	hour	yd	yard
ha	hectare	$>$	greater than
Hg	mercury (pressure)	$\ngtr$	not greater than
hp	horse-power	$<$	less than
h	hour	$\nless$	not less than
in.	inch	$\propto$	proportional to
in^2	square inch	$\sim$	of the order of
i.d.	inside diameter	$^\circ$ $'$ $''$	degree, minute, second (of angles)
kWh	kilowatt hour		

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

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