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TAILORING TO THE REQUIREMENTS OF A GRANULAR INSECTICIDE:

THE DEVELOPMENT OF THIMET* PHORATE GRANULES

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INTRODUCTION

Insecticides formulated as granules were first used experimentally in the 1950's. Today several well known insecticides are available in granular form. The sales figures for these materials give adequate proof of their suitability and acceptability.

Granular formulations of systemic insecticides have many advantages over liquid or wettable powder formulations. Persistence is increased, since the insecticide is released gradually from the granule carrier; with suitable machinery very precise placement of granules is possible; concentrations in the soil are retained after placement; less drift occurs during application than with dusts or sprays; granular chemical application equipment is easier to use and less costly to maintain that spray equipment; granule applicators can be attached to planting machines, seed drills or cultivating machinery thus saving a separate operation; granular chemicals are pre-mixed, ready to use, which means no mixing, no measuring, no water to haul; granules are easy to apply from the air; in granular formulation the toxic hazards of insecticides to operators and to animals and beneficial insects is reduced.

THIMET phorate was one of the first insecticides to be used in granular form and was first registered in the United States in 1959 for use on potatoes and in Great Britain in 1962 on potatoes and sugar beet. Phorate granules are now used in many countries on a wide range of crops. In Great Britain recommendations are made for the use of phorate granules on potatoes, sugar beet, carrots, brassica crops, field and broad beans, strawberries and sweet corn.

Phorate is an organo phosphorous insecticide which relies for its effectiveness on a combination of systemic and contact action. The compound is absorbed from the soil by the roots of plants, or, following foliar application, through the leaves. The translocated insecticide is moved to all parts of the plant. Following foliar application, contact toxicity is derived from fumigant action of the compound. Phorate has a high vapour pressure but a low water solubility. The acute oral LD_{50} to male CFN strain rats is 3.7 mg/kg.

How do these properties of phorate relate to granule requirements? The compound has a high mammalian toxicity as a technical material or in liquid formulation, but formulated as a granule the operator hazards are substantially reduced. In the U.K. the demonstration of this reduction of toxic hazard has resulted in the relacing of protective clothing requirements for phorate when formulated as a granule containing no more than 10% of active ingredient. Phorate is a Part II scheduled substance in the Agricultural (Poisonous Substances) Regulations. The granule formulation allows accurate placement of granules in the developing root zones so that systemic uptake is achieved. Release of active ingredient by vapour pressure

* Trademark of American Cyanamid Company

from the granule surface gives an immediate knockdown to aphids infesting plants that have been given a foliar treatment of granules. Beneficial insects such as bees are able to escape this effect, presumably by moving out of the immediate vicinity.

To be suitable as a granular carrier a candidate material must meet requirements in respect of size, shape, flowability, spreadability, stability, hardness and release. In this respect several alternative materials are available including sand, pumice, sepiolite, olive pips and clays of several sorts, such as attapulgite, celatom and Fullers' earth.

DEVELOPMENT OF THIMET PHORATE GRANULES

Choice of granule

The granule originally chosen by American Cyanamid Company for Thimet phorate was attapulgite of mesh 24/48. Attapulgite is an absorbent attapulgus clay; chemically an aluminium magnesium silicate. The 24/48 mesh size contains 7,722,000 particles per pound (17,024,096/kg) of granules. Early development work in the U.K. was carried out with the attapulgite formulation, but it was subsequently established that this granule with a high proportion of fine particles would not pass the M.A.F.F. specification of a granule to qualify the formulation for relaxation of protective clothing requirements. A change was, therefore, made to Fullers' earth as a carrier; SYK 22/44 mesh granules being chosen. This granule contains 5,000,000 particles per pound (11,023,113/kg). It is an extra hard, water stable granule, with a base exchange capacity of 50 - 60 and surface area of 110 - 120 m^2/g. Since 1964, this granule has been used exclusively for all commercial and experimental samples of Thimet phorate granules in the United Kingdom.

APPLICATION METHODS

The different techniques of granule application and the machines available for effecting them were very adequately described by Makepeace (1965). Phorate granules may be applied into the planting furrow for potatoes and for brassica transplants; into the seed furrow for field and broad beans and sweet corn; as a band in front of the seed coulter for carrots; topically over the row for sugar beet and strawberries, or broadcast over the foliage for field and broad beans. The Horstine Farmery Microband Applicator described by Makepeace has continued to be the machine used almost exclusively for down-the-row placement of granules whether applied into the soil, with the seed, or over the row. Adaptations have been devised for such techniques as the deep placement of granules and drilling bands of granules under the seed. Since 1965, some new machines have been introduced for the broadcasting of granules, amongst them the Horstine Farmery Airflow which combines the metering mechanism of the Microband with air assisted movement of the granules to outlets on a boom. This machine mounted on a high-clearance, narrow-wheeled tractor has been used extensively for the application of insecticide granules to field beans. For the field bean crop, aircraft have also been widely used for applying granules.

Close co-operation exists between the chemical companies manufacturing insecticide granules and the machinery manufacturers. Over the past ten years in the U.K. the development of granules and of the machines to apply them have gone hand in hand. Neither commodity has much future without the other. In such matters as the calibration of machines for particular types of granule there is particularly close co-operation.

Studies on the mode of action of disulfoton on sugar beet, potatoes and brussels sprouts were reported by Walker (1963). No such complete report has been presented for phorate. Studies have been carried out by several different workers at widely dispersed centres.

Effects of soil type and moisture

In a study of the fate of phorate in soils, Getzin and Chapman (1960) used radio-active tagged material. One hour after treating various soil types, these investigators found that 25, 20 and 10% of the radio-activity applied had been lost through volatilisation from sandy soil, silt-loam and organic soil, respectively. After one hour, little or no further volatilisation occurred. They reported that phorate when applied to the soil is partially oxidised, hydrolysed and bound to the soil. They observed that phorate was more available to plants in sandy soil than in clay loam. Lindley (1963) showed that factors influencing the biological persistence and effectiveness of phorate were rate of application and soil type; mineral soils required lower doses than organic soils.

Investigations at Rothamsted Experimental Station provided information demonstrating that phorate moved readily in the soil in the vapour phase (Bardner and Burt, 1962; Etheridge and Burt, 1963) as well as in drainage water (Bardner et al, 1963). Water can also influence the results of soil application of systemic insecticides. For root absorption to take place some water must be available in the soil. In 1962, Bardner and Burt reported that soil treatment of potatoes with phorate, menazon, dimethoate and disulfoton gave good aphid control during a wet season. However, in a dry season menazon and dimethoate were less effective. It was suggested that phorate and disulfoton could move in the gaseous phase in both dry and wet soil. Results from further experiments with wheat seedlings indicated that phorate and disulfoton were sufficiently volatile for toxic quantities to move in the vapour phase and enter roots either directly, or through the water in which they were placed (Ibid, 1962; Etheridge and Burt, 1963). That phorate and disulfoton were less dependant on soil moisture than dimethoate or menazon was further demonstrated by Etheridge and Graham-Bryce (1967).

Working at Imperial College Field Station, Way and Scopes (1968) observed the effects of soil-applied systemic insecticides on soil fauna. They showed that in-row phorate distributed along a 1.5 in (38 mm) wide band of soil, 3 in (76 mm) deep, killed Collembola 3 in (76 mm) on either side but not 6 in (152 mm) away. It did not spread upwards in toxic quantities, but after rainfall, sufficient amounts to kill Collembola leached at least 3 in (76 mm) downwards. It was suggested that upwards movement was related to volatilisation.

Placement of granules in soil

The foregoing studies indicated that the correct positioning of granules was essential if the plant roots were to have ready access to insecticide. From the work of Way and Scopes it would appear that 3 in (76 mm) was the maximum distance that granules should be placed from the seed or developing roots. Gerhardt and Turley (1961) observed that young potato plants growing in a dry region did not pick up phorate from granules placed 2 in (51 mm) below and 4 to 5 in (102 - 127 mm) to one side of the seed pieces until the field had been irrigated. Burt, Broadbent and Heathcote (1960) found that the aphicidal efficiency of Thimet applied as individual doses separated from the tubers by distances of up to 6 in (152 mm) decreased as the distance increased, but the effect of distance became less as time passed.

Considerable work has been carried out at the National Vegetable Research Station at Wellesbourne on the most effective positioning of insecticide granules for carrot fly control. This has been reported in successive Annual Reports of the research station since 1960: the work was carried out by D. W. Wright up to 1967 and has been continued by G. A. Wheatley since that date. The recommended method of application of phorate on carrots is to apply a 3 in (76 mm) wide band of granules immediately in front of the drill coulter (bow-wave technique). In this way granules are mixed into the top few centimeters of soil by the passage of the drill coulter through the band. The method has proved commercially acceptable for several years. Work at Wellesbourne in 1966 examined the effect on carrot fly control of phorate applied at depths of 10, 25, 50, 100 and 250 mm below the carrot seed. It was found that depths of placement less than 50 mm reduced the effect of phorate, whilst greater depths did not bring about an improved effect. It was suggested that insecticidal effect depended on the pick up of insecticide by the roots and its translocation to the feeding sites of larvae. Similar work was carried out at Wellesbourne in 1968 and also on organic soil at Mepal. The maximum performance of phorate was obtained when placed 4 in (102 mm) deep in organic soils and 2 - 3 in (51 - 76 mm) deep in mineral soils. Granules placed along the rows of the growing carrot crop may increase the persistence of phorate for late-harvested crops.

Foliar Applications

For foliar applications of granules two types of insecticidal action have to be considered: fumigant/contact and systemic. Fumigant activity can either be as a direct contact action on the insects or an indirect systemic one; the phorate having entered the plant in the vapour phase. The fumigant/contact action of phorate was demonstrated by Cook (1959) and the fumigant/systemic effect by Geering (private communication, 1962). Reynolds et al (1960) state that the foliar activity of phorate is largely a combination of fumigant and systemic activity. Investigations are currently in hand at Rothamsted (private communication, Graham-Bryce, Stevenson and Ethridge) to thoroughly investigate the mode of uptake of both phorate and disulfoton in field beans in relation to rainfall and to the type of granular carrier used. The toxicity of plants to aphids is assessed by caging *Aphis fabae* on leaf surfaces for 24-hour periods at intervals during the experiments. Preliminary results have given peaks of activity corresponding to initial fumigant effect, to a leaf systemic uptake and to a root systemic uptake. This is the first critical examination of its kind on field beans involving phorate. The outcome of the investigation should throw light onto the most desirable positioning of granules to obtain the required effect. In commercial practice the objective is to distribute granules evenly over the crop so that they lodge in the foliage and leaf axils. In due course many also fall on the ground. Such commercial applications either from the air or from the ground have given very acceptable results.

BIOLOGICAL STUDIES

Early trial work with phorate in the United Kingdom has been reported on sugar beet for the control of aphids (Lindley, 1961), on potatoes for the control of aphids, and on carrots for the control of aphids and carrot fly, *Psila rosae* (Lindley, 1963).

Initially, applications to sugar beet were in the form of granules applied into the seed furrow. This treatment proved phytotoxic, particularly on sandy soils, therefore foliar and side band applications were investigated. Side band applications did not give as good control of aphids as over-the-row foliar treatments. From this early work stemmed the current recommendation for sugar beet: 10 lb 10% granules/acre (11.2 kg/ha) applied over the row soon after singling for up to four weeks control of aphids.

On potatoes, granules were applied into the furrow and covered with the seed tubers at planting time. Control of aphids for 12 - 14 weeks was demonstrated. From this work stemmed current recommendations, which are varied according to soil type and the type of potato (early or main crop) being grown.

On carrots, phorate was phytotoxic when applied in a narrow band in the drill but not when a band of granules was placed above the seed. Trials showed that 15 lb 10% granules/acre (16.8 kg/ha) on mineral soils applied as a band at the time of drilling controlled aphids for 8 weeks and carrot fly for the whole season. This type of application at a higher rate of use has since been extended to carrots grown on organic soils.

Seed furrow treatments were shown to be phytotoxic on sugar beet and carrots, but on sweet corn this type of application was shown to be safe and to effect a good control of frit fly (Oscinella frit) by Jepson and Mathias (1960). Subsequently, this type of application came to be recommended also for the control of aphids and pea and bean weevil (Sitona lineatus) in late-sown broad beans and field beans.

The foliar treatment developed for sugar beet was employed in trials on strawberries, field and broad beans, and on brassicas for aphid control. From this work came an over-the-row foliar treatment for strawberries for aphid control and a broadcast foliar treatment for aphid control in beans. A foliar treatment on brassicas was also introduced in 1964, but was later withdrawn following erratic commercial results. The suitability of Fullers' earth SYK as a granular carrier for phorate treatment to brassicas was held up to question.

Trials were carried out for the control of cabbage root fly (Erioischia brassicae) and aphids on transplanted brassicas following the application of a band of granules into the planting furrow (Caldicott and Lindley, 1965). Cabbage root fly damage was found to be reduced and a control of aphids obtained for approximately eight weeks. This treatment is now used commercially for late planted brassica crops which are subject to aphid infestation shortly after planting out.

The most recent development of the use of phorate granules is the employment of double rates (30 lb 10% granules/acre, 33.6 kg/ha) to potatoes as a planting furrow treatment for wireworm (Agriotes spp.) control (Caldicott and Lindley, 1965; Caldicott and Isherwood, 1967).

FUTURE OUTLOOK ON GRANULAR INSECTICIDES

One controversy which still has to be resolved is the choice between application rates on an area basis and application rates on a linear basis where down-the-row treatment is concerned. Most of the original trial work was carried out on a rate per acre basis, a rate which puts on a variable amount per unit length of row depending on the row width. It can be argued that it would be more realistic to apply a standard rate per unit length of row which on an area basis varied according to row width. A meeting to discuss this subject was held at the National Institute of Agricultural Engineering, Silsoe in February, 1964. Although it was decided that a change to a linear application rate would be desirable, in fact few changes have been made by manufacturers. The more recently introduced recommendation for the treatment of brassica transplants with phorate adopted a linear rate, but the well tried recommendations on other crops have stayed as they are, to avoid the complications that would be involved in changing over.

Another sphere in which more work needs to be done is the development of techniques for measuring granule distribution. Such investigations fall into the 'no man's land' between the machinery manufacturers and the chemical companies and have not been properly tackled. Basic studies of this sort will benefit the development of future granular insecticide formulations of which it can be confidently assumed there will be many.

SUMMARY

The choice of a granule carrier for phorate is discussed and a review made of some biological results and mode of action studies in relation to soil and foliar applications.

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A REVIEW OF THE DEVELOPMENT OF A GRANULAR SYSTEMIC INSECTICIDE BASED ON DISULFOTON

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INTRODUCTION

The purpose of this report is to summarise the work done by Baywood Chemicals on the development of granular formulations in the U.K., mainly based on products containing disulfoton as the active ingredient (a.i.). Disulfoton is one of the many interesting organophosphorous insecticides developed by Schrader (1950). Its systemic properties were established and first reported by Unterstenhofer (1957). Disulfoton is only slightly soluble in water, has a volatility of 2.7 mg/m^3 at 20°C and an oral LD_{50} of 12.5 mg/kg and 2.6 mg/kg respectively on male and female rats. It was introduced commercially in 1963 as a 5% formulation based on pumice. Further development led to a 7½% granule on pumice followed in 1970 by a 10% formulation on Fullers' earth for soil application only. Rates of application in terms of active ingredient have remained constant throughout and vary from 0.7 - 1.5 lb/ac (0.78 - 1.7 kg/ha) depending on the particular crop. Disulfoton controls aphids on a wide range of crops including potatoes, beet, brassicas, carrots, parsnips, celery, broad, runner, field and french beans, marrows and strawberries (Baywood Chemicals Limited, 1963). By effectively controlling aphids over prolonged periods reduction in aphid transmitted viruses can be achieved. Apart from aphids, other pests such as carrot fly, leafhoppers, mangold fly and flea beetle are controlled. Details of biological results, mode of action and application have been published (Linke, 1964; Linke et al., 1961; Forrest et al., 1963). This paper will merely pick out the salient points arising out of a very intensive and extensive laboratory and field project.

FORMULATION

Disyston* marks an interesting and major development in pesticide formulation. The active ingredient is highly toxic and would be hazardous to apply as an emulsifiable concentrate unless substantial protective clothing were worn. As a seed dressing, as it was tested initially, it was phytotoxic to sugar beet although safe on cotton. It was, therefore, formulated as a granule on pumice, this material being readily available as small pebble-shaped granules from deposits along the Rhine valley. This formulation, containing 5% active ingredient, was shown to be non-phytotoxic when applied to soil and gave good aphid control by systemic uptake through roots. It provided a product of low concentration which was much safer to handle than the emulsifiable concentrate.

* Disyston is a Registered Trade Mark of Bayer Germany

Baywood conducted extensive trials and soon discovered its effectiveness as a foliar and soil treatment.

At about the same time it became apparent that the Rhine pumice mines could not supply sufficient material for pesticide needs and supplies were sought elsewhere. Alternative materials such as attapulgite, Fullers'earth and Sicilian pumice were investigated. Tests showed that for foliar application pumice was essential for effective aphid control and that Sicilian pumice was of excellent, if not better, quality than Rhine pumice, for both soil and foliar applications. The optimum particle size range was determined at the same time. The number of granules per pound varies to some extent, but is for commercial pumice formulations, approximately 2.5 million (5.5×10^6/kg). Fullers'earth SYK 22/44 has a count of approximately 5 million per pound (11×10^6/kg). Various workers have shown that correct use of solvents and emulsifiers in the formulation is important and that on certain clay based granules, particularly attapulgite clays, a proportion of the active ingredient is 'locked up' in the clay molecule unless the correct solvent is applied first to act as a buffer. This is much less important with pumice, but the solvent may still assist in evaporation of the active ingredient which is important for both foliar and soil applications. Work at Rothamsted Experimental Station (1963, 1964, 1965) has shown the ability of disulfoton to move through the air spaces in the soil and be absorbed in the vapour phase by the roots. The emulsifier is also important in permitting mixture with soil moisture.

Notification under the Ministry of Agriculture, Pesticides Safety Precautions Scheme proved a problem as the active ingredient was of sufficient toxicity to qualify for inclusion as a Part II substance in the Agricultural (Poisonous Substances) Regulations, application and handling requiring full protective clothing. While the Ministry accepted in principle that a 5% or 10% granule afforded much less risk than a spray because of the great reduction in the possibility of inhalation or skin absorption (a granule does not easily stay on the skin, and the contact area is small), they were unable to alter the law of the land. Cyanamid of Great Britain were confronted with a similar obstacle with phorate granules and The Association of British Manufactures of Agricultural Chemicals supported the contention that provision should be made for relaxing precautions when circumstances warranted it.

Industry carried out a series of exposure tests whereby the blood of workers applying and handling disulfoton and phorate granules was tested; the Ministry examined dust and vapour hazards from granule applications, and joint exercises were also conducted. Lloyd and Bell (1967) report one example of this which involved the sampling of air from areas around a field in which granules were applied by aircraft. Collaborative tests on methods of analysis for particle size and attrition were also carried out.

One of the most difficult single problems was the legal definition of a granule, but the final result, now incorporated in the Regulations, is both clear-cut and reasonable:

"Specified substance in granular form" means a preparation -
(a) which consists of absorbent mineral or synthetic solid particles impregnated with a specified substance, the size of the particles being such that not more than 4% by weight of the preparation is capable of passing a sieve with a mesh of 250 μm, and not more than 1% a sieve with a mesh of 150 μm
(b) which has an apparent density of not less than 0.4 g/ml if compacted without pressure; and
(c) not more than 12% of which by weight consists of a specified substance.

MODE OF ACTION

The mode of action of disulfoton applied in granular form can be influenced by various factors such as (i) the intrinsic properties of the active ingredient, (ii) type of inert carrier, (iii) type of application, (iv) habit of growth of crop i.e. habit of foliage and root system. Critical work elucidating the implications of these factors was reported by Walker (1963) who worked mainly with 3 crops: sugar beet, Brussels sprouts and potatoes. Disulfoton granules can either be applied to the foliage or to the soil at drilling or planting time and the mode of action differs with each method.

Foliar application

In foliar application some granules will be retained by plants and some will fall on the soil surface. Disulfoton can be released to give aphid control in a number of ways which can be summarised as follows:-

(a) On the foliage: (i) direct fumigant action on aphids from granules on plant or soil surface, (ii) aphids feeding on leaves absorb disulfoton from granules on their surface, (iii) aphids feed on leaves which become toxic by penetration and translocation of disulfoton from other plant sites e.g. leaf axils.

(b) On the soil surface: (i) direct fumigation, (ii) aphids feed on leaves which have absorbed disulfoton vapour from granules on the soil, (iii) aphids feed on leaves which have become toxic by root absorption and subsequent translocation.

With foliar applications the relative granule distribution and retention can be influenced by type of plant, stage of growth, weather at application and afterwards. On sugar beet more granules were retained at 7 - 8 leaf stage than at earlier stages and the systemic effect was longer. This had practical implications in that if aphids appeared at an early stage a split application (2 x ½ rates) with a 3 - 4 week interval between gave a longer systemic effect than a single full rate. Absorption from the soil through roots is variable and depends to some extent on heavy rain or irrigation after application.

Brussels sprouts are treated at a later stage of growth than sugar beet and more granules may be retained by the foliage. Wind and rain could be important factors in removing granules from the foliage. However, as the roots of Brussels sprouts are close to the surface there is more chance of root uptake than with sugar beet. Generally, aphid control is effective for 6 weeks. In field and broad beans Walker (1963) showed that it was mainly the granules held by leaves which were important for aphid control as beans have deep tap roots and it is unlikely that disulfoton would reach them. Better retention of granules is obtained where plants are grown in narrow rows and have a continuous canopy which acts as a good catchment area. Poor aphid control has resulted where granules have been applied on beans under windy conditions at a time when the crop had not met in the rows. On carrots, because of the feathery foliage, fewer granules remain on the foliage and initial aphid control is probably due to fumigant effect, assisted later by root uptake.

However, most carrot applications are to the soil at drilling and by this method good carrot fly and aphid control is achieved.

Walker also found from his critical trials that in foliar applications pumice based granules gave quicker release and better results than Fullers'earth. It was for this reason that the original formulations were based on pumice to cover foliar and soil applications. Now a 10% Fullers'earth formulation has been introduced but for soil application only.

Applications into the soil

These are carried out at or before planting or drilling. Aphids are controlled by feeding on leaves which have become toxic by root absorption and subsequent translocation. To demonstrate the mode of action in potatoes Walker (1963) used a two pot technique and was able to show that the disulfoton was absorbed into the plant from adventitious roots with negligible absorption from the 'seed' tuber itself.

Soil applications have given longer persistence and prolonged control of up to 16 weeks on potatoes and 12 weeks on transplanted brassicas. Carrot willow aphid and carrot fly control has been achieved by applying disulfoton granules in the soil at drilling time. It is important that the granules are placed at the correct site for absorption. This can raise difficulties and for example it was found impracticable under field conditions to place granules 2 in (50 mm) below the seeds of field beans.

Trials have indicated little difference in control when comparing soil application of pumice and fullers earth granules.

APPLICATION

In the initial development stage of granules there were no suitable applicators available in this country and the first field trials work was carried out with two imported American machines, namely the Noble Granular Applicator and the Gandy Granular Applicator. However, it was not long before a British machine, the Horstine Farmery Microband Applicator, came on the scene. This machine was an adaptation of an existing fertilizer applicator which could be fixed to a tractor hoe and used for top-dressing arable crops such as sugar beet. These three machines, which meter out a continuous band of granules, were compared in critical tests. The Horstine Farmery Microband was found to be the most suitable and is now the most widely used applicator in the United Kingdom for band treatments (National Institute for Agricultural Engineering, 1962). The hoppers can be readily mounted on a range of farm machinery including planters, seed drills, tractor hoes and tool-bars. By the use of special coulters a band of granules can be placed in the soil below or to the side of seed or plants. The early work on application of granules, including machinery and placement, was well described by Makepeace (1965). Work done in Germany at the same time has been reported by Stiemerling (1966, 1966) and reference is made to the use of applicators such as the Cramer which, instead of metering a continuous band of granules, releases a given dose at each planting point. Planters fitted with such devices are used in the "seed" potato producing areas of Germany. This "spot" application can raise problems and care must be taken to ensure that the correct dose per acre is applied. In New Zealand, Rough and Close (1965) have reported the use of disulfoton granules applied to potatoes using either the Horstine Farmery Microband Applicator or the Griffiths. Recent introductions in the British market have been potato planters such as the Howard Smallford Rotaplanter, Cramer and Hassia with "built-in" granular applicators.

For broadcast foliar applications on crops such as Brussels sprouts and field beans a range of fertilizer spreaders were tested and the Vicon Vari-Spreader (pendulum action) was found to be the most suitable for applying low rates of granules accurately with a swathe width of 4 or 6 yard (3.66 or 5.48 m) depending on the length of the reciprocating spout. It was found that more even application over the swathe was obtained if a wind shield was fitted. A range of spinning disc fertilizer spreaders have been tried with variable results but the Amazone ZA, Alpha-Accord Wittekind and the Blanch-Lely have been used successfully to apply disulfoton granules in the field.

A recent development for broadcast application is the Horstine Farmery Airflow Applicator which can give a swathe of 32 ft (9.73 m) and mounted on a high-clearance tractor has been used widely by contractors for granule applications to Brussels sprouts and field beans. This machine has the same force-feed metering device as the standard models but instead of dropping by gravity the granules are blown by a blast of air from a fan to specially designed impact nozzles.

In recent years there has been an increase in usage of disulfoton granules from the air, particularly on field beans where aphids can build up quickly and control measures must be expedited quickly. Disulfoton granules are most suitable for this application as Free, et al. (1967) showed that when applied to field beans in flower, bees were not harmed either after application or later when disulfoton became systemic in the plant. Application is mainly by fixed wing aircraft and has been reported by Myram and Forrest (1969). Work has been reported by Courshee and
I Ireson (1962) and Hill and Johnstone (1962) on the development of special equipment for granular application by helicopter. Helicopters fitted with the Management Aviation Evergreen Space Spreader were used to apply disulfoton granules on field beans in the United Kingdom in 1969.

CONCLUSIONS

Granular insecticides such as those based on disulfoton, have opened up a new and often more accurate method of insect control. They have been rapidly accepted by farmers and growers since their release on the British market some 8 years ago, as they offer many benefits to the farmer over liquid spray applications. These benefits include:- ease of handling, longer persistence due to slow release, no drift, less hazards from a toxic active ingredient to operators, wild life and beneficial insects, two operations can be carried out at the same time, selectivity is improved and there is no water to carry. Work is also under way with granules in the herbicide field and further developments may be expected in the future. Although granules can be applied fairly accurately at present, requirements may become more demanding in the future as the chemist and agronomist "tailor-make" pesticides which must be placed more precisely either to the soil or the plant itself.

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THE MECHANICS OF GRANULE APPLICATION

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INTRODUCTION

The effectiveness of a pesticide is dependant on the material being in the right place at the right time, and in the correct amount. In the case of agricultural chemicals this is particularly important when the toxic hazard to the plant can only be avoided by precise application.

The active chemicals are generally applied in a suitable diluent so as to make application easier and more uniform and sometimes to assist in biological response. As a cheap, readily available diluent, water has been the obvious choice, but in an increasing number of cases water is being replaced by a solid carrier. One reason for this is that a solid carrier can be made to possess uniform characteristics and the dilution is a chemical manufacturers operation, NOT a field approximation. Once in the field there are several advantages to be gained from using a granular formulation of a chemical.

The biggest use so far in the United Kingdom and other countries, has been in the field of insecticides. This is due to two factors; the highly toxic compounds being used and the need for precise positioning of the chemical. Both safety and accuracy are now beyond question.

Despite the present lead of insecticides, it seems only a matter of time before granular herbicides are the market leaders. By this, I do not mean that liquids will be excluded to the same extent as has happened with insecticides but rather that granules will be used for applications where liquids have not proved suitable. Whenever root translocated herbicides are used, granules have many advantages. For instance in the growing crop the bulk of the granules will pass through foliage and they can be placed more precisely with less sophisticated equipment. Perhaps, not so obvious is the fact that the more volatile chemicals can be released progressively, this reducing the risk of the active ingredient being washed away, or lost as vapour.

The mammalian toxicity of herbicides unlike that of insecticides, is not generally very high, and therefore, more scope is available in the choice of granules, for instance, softer and cheaper granules can be used because one is not faced with a toxic dust hazard. Contrary, then, to many people's belief, granular herbicides should not be held back by the cost of granules because the cheapest granules can be used. Fabricated granules, (prills and extrusions) are already widely used and will no doubt gain much more ground and bring even more refinement to techniques used. Drift, which is such a hazard with liquid sprays, is very much reduced when granules are used. Granular herbicides can be applied on many days in spring when the weather would stop spraying. The lack of drift also makes granules the formulation of choice when there are unusually susceptible and valuable crops in the vicinity.

Granules are so convenient to handle, that the application can often be combined with some other operation - sowing or fertilizer application; providing positive displacement equipment is used, variation of travelling speed will not affect application rates.

Unquestionably, the last word on how to apply the granule must come from the chemical manufacturer. The machinery manufacturer, however, should not only make himself available to advise on his own equipment, but should also try to understand the biological aspects. A little knowledge may be a dangerous thing in some walks of life, but the man who understands the mode of action of the material being applied will undoubtedly do a better job of designing equipment for applying granules. He must not involve himself in the merits of various products but he must have as much knowledge as possible of the group of products with which he is working. For instance he must know if there are phytotoxicity problems and if volatile properties are to be exploited. There is also the positioning of the granule for uptake by roots or surface availability. The cost of granules is such that maximum use must be made of material used, and therefore, placement has to be considered from this angle as well. For instance, in the case of expensive, but highly effective materials, spot treatment must be considered. If the accuracy of such treatment falls short of that of band application, then this saving must be compared with losses incurred in having untreated plants.

The idea that granules are an expensive means of pest control is widely held, and the problem today is one of reducing costs. Tomorrow's problem may well be different when once the benefits are fully understood and evaluated. Tomorrow's agriculture will demand that certain techniques be used; then chemical and machinery suppliers must develop more sophisticated techniques and equipment. Today we think first in terms of accurate metering and then of the adaptability of the machinery to other implements, with the ever constant problem of price never far away. Tomorrow the application of granular pesticides will be fully integrated into the process of growing crops and consequently the farmer will judge such equipment as a standard tool of agricultural practice.

Examples of this increase in scope may well be as follows:-

Herbicides:

Band applications of liquids are at the moment cumbersome, over-reliant upon the weather, and lacking in accuracy. The use of granules overcomes all these difficulties; for instance, if the correct machine is used one automatically gets the pre-determined amount of active ingredient irrespective of forward speed. The matching of nozzles is replaced by the matching of rotors, and the manufacturer guarantees this. Sophistication will come with equipment for mixing the granules with the soil at pre-determined depths. There would of course, be considerable scope here for also incorporating insecticides and nematacides at the same time as the herbicides. The incorporation equipment could enhance the seed bed by breaking down the soil clods and may well make the sowing of such crops as sugar beet a one pass operation.

Broadcasting granules for weed control demands a good ground pattern at a high working rate. The low-weight pay load helps the latter but the ground pattern must be studied thoroughly. Because the technique is akin to the spreading of fertilizer, observers tend to go by looks and assumption, but the consequences of variations in rates and patterns can be far more serious with herbicides. Also the amounts of material applied are so low that the operator cannot be expected to do his own calibration. It is imperative that the machine should be pre-set and of a known performance. Only by extensive use of trays and accurate weighing of each individual tray can you ensure that the granules are being evenly distributed.

Because many herbicides travel very little laterally in the soil, the problem of pattern cannot be over stressed. Only a good liquid spray nozzle can equal the performance of our latest pneumatic nozzle. A feature of broadcast granules is their ability to penetrate foliage and this has been tried in England for post-emergence treatment of sugar beet. Perhaps the best example is however, in the Canadian Prairies, where soil erosion is a problem and wheat is often sown into established weeds for cover: granules can be used to penetrate this cover to selectively remove wild oats.

Insecticides:

The entomologist's requirements would appear to be well catered for up to a point. We have got excellent, low priced equipment for row work, but a lot of development is however required on means of placing granules in the soil alongside seed or plant rows, especially the latter. Although some plants will tolerate root disturbance, many will not, and in most cases there is a serious risk of root deformity. If we were to accelerate the granules to such a velocity that they would penetrate the soil to a required depth this would open up many possibilities. For instance, late generations of cabbage root fly could be controlled even after first signs of damage have appeared. By varying the velocity in relation to the soil density the depth of penetration could be adjusted. These factors would of course be useful with herbicides and nematicides.

The age old problem of stalk borer in maize provides an ideal opportunity for granules to show their superiority over liquids. When liquids are used for control they remain at the point where they contact the leaf, unless used at very high volume; in the more arid countries, water is too precious for this method. On the other hand, granules can be applied with inexpensive equipment in a band directly over the plant "funnel". The rolling action of the granules brings them down into the leaf axils exactly where they are required. By this method the waste is minimal, the rate of work high and machinery costs low. Increased use of the equipment can be made by using it also for band placement of herbicides.

Fungicides:

Now that systemic fungicides are with us, the problem of getting them to the target area may well be another job for granules. Seed treatment of cereals is already quite complex and the application of yet another dressing may prove to be more than the seed can carry. Granule application may however, prove difficult due to the problem of incorporating the machinery onto the seed drill. So far on other crops granule applicators have been incorporated onto existing machinery. In this case we may well ask for a little co-operation from the farmer and implement maker.

Molluscicides:

The tremendous success of new materials in this field have proved the versatility of granules. The bran-based extrusion seems to have everything and spreading is simplicity itself. As much of this is used on small market garden plots hand held equipment has proved simple and efficient.

Nematacides:

Perhaps here lies the biggest challenge yet, especially as current materials are extremely poisonous. Nevertheless, uncomplicated techniques and machinery at the moment being evaluated will mean that the granule never sees the light of day during both transport and application. Because it seems inevitable that mono-cropping will come in due course, because of the concentration of crops around processing factories, it is essential that this problem of nematode control is solved in the near future. In South Africa, where their higher soil temperatures facilitate the use of nematacides, there is ample proof that mono-cropping of potatoes is feasible. If, as can be expected, the granule enables us to use materials which are virtually impossible to apply safely by any other means, then all the work that has gone into their development should really show its worth.

Micro-Granules:

These must not be confused with their larger brethren, since they are a completely different approach to the application of active ingredient in solid form. They have their own problems and their own virtues from the engineering angle. Rightly or wrongly, granules are sometimes accused of insufficient ground cover. Here we are working with particles as low as 100 - 500 microns, thus giving us the necessary cover. On the other hand the lighter the particle weight the more likely it is to remain airborn and drift. This low particle weight also means that less kinetic energy can be stored, thus presenting problems when gravity is insufficient to carry it to its target. Calibration and hopper bridging may well bring problems. Nevertheless, as in other cases, if they are biologically desirable then the engineer must find a way of applying them. Although we have yet to do commercial application, tests so far suggest that we can work within the chemical manufacturers requirements.

APPLICATION MACHINERY

Gravity Machines:

These must have outputs predictable to within 2 - 3%, give accurate cut-off, t tolerate abrasive materials, and be versatile.

Pneumatic Machines:

The obvious choice for hitting the inaccessible target. When used for broadcasting it enables folding booms to be used, thus vastly increasing the work rate. Not so obviously, it allows a higher flow rate at the point of calibration, thus eliminating the main problem of the full width spreader. Despite the simplicity of the final product, our own machine proved to be the most difficult design operation we have ever undertaken. Much has been written about "fluidics" but we still had a tremendous amount of basic work to do. The air velocity must be equal in all nozzles as must the quantity of granules. By introducing the granules after the air is trained in the pipe and by giving each pipe its individual air supply we achieved this. Our problem was then to design a nozzle that could perform accurately. Only after extensive trials chiefly associated with the reaction of the granules in the air stream have we been able to predict the ground pattern. As far as we can see, at the moment we shall require each new granule at our works for performance testing. Nevertheless, having done this, we can now give quite a firm recommendation for accurate application. I would warn anyone considering this equipment that visual tests are useless and that the whole subject of pneumatic application is bedevilled with misleading assumptions and statements. To achieve ground patterns on 4 in (102 mm) test trays with over 90% within 15% of mean calls for extreme accuracy in both design and manufacture.

Aerial Applications:

Much is already done by aircraft where large acreages are involved. The working rate is excellent because of the compact pay load and turn round time is at a minimum. The advantage over the ground machines lies chiefly in the avoidance of crop damage, as, for example, when treating beans with insecticide.

Against this however must be considered the economies of accuracy. Ground machines can operate easily within a 3% tolerance which allows close tolerance materials to be used. Excess application of as little as 10% can remove all profit. If all the tolerance has to be below this, then one risks failure. Can an aircraft fly within these tolerances? With varying wind speeds, ground conditions and other related problems there must be doubts. Insecticides have been successfully applied but errors with them are not so obvious as with herbicides.

ECONOMICS

The chemical is judged on what it is worth, being expendable, with an annual profit for the manufacturer and user. Machinery is a "once and for all" sale with only one profit for its manufacturer. To "squeeze" the machinery profit will inevitably slow development. The really safe way of keeping this margin healthy is for joint marketing. It may be wrong to comment on this during technical discussion, but everyone should play their part in avoiding the disjointed state of affairs existing in the liquid field. The farmer should be presented with a tightly knit packaged deal in which the costings are viewed over-all. Surely it is wrong for the chemical company to go through all the expensive complexities of development, manufacture and distribution merely to see it all nullified in application. It is surely right that the manufacturer has the maximum control possible at this vital stage. One has only to see liquid chemicals being squirted onto crops through obsolete and unsatisfactory equipment to realise that this must be avoided from the beginning in granule application. Are then these remarks so inappropriate, especially as it is usually the technician who sorts out the aftermath and not the salesman who may be on his way to creating a second such situation.

THE FUTURE

It is a matter of the greatest urgency that a study be made of the physical properties of granules in relation to various cultivation techniques. Only after such work shall we know that applying granules in such a position makes the best use of the active ingredients they are carrying. At the moment there is too much complacency due to the measure of success so far. Optimum use is essential for pest control, excessive use is wasteful and often dangerous, harming plant growth and leaving undesirable residues.

SUMMARY

(a) Granules are relatively expensive and therefore one pays dearly for inaccuracy.

(b) Granules are justified where liquid applications are unsuitable or cannot be produced.

(c) Granules must be considered and treated in their own right, and not related to either fertilizer or liquid pesticides application.

(d) Granules are not only a vehicle, but also a part of a biological process.

(e) Granules can offer safety to operators when other formulations would be positively dangerous.

(f) Granules used with the correct equipment are predictable.

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METERING AND DISTRIBUTION OF COARSE AND FINE GRANULES

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In agriculture granules are used as fertilizers, plant protection materials, granulated feed-stuffs (pellets) and granulated seeds (calibrated, made into pills).

A common classification of granules is given in Fig. 1.

Figure 1

Classification of granules

Agriculture		Chemical Engineering
2 ··· 5 mm	coarse granules	10 ··· 50 mm
0,3 ··· 2 mm	fine granules	2 ··· 10 mm
0,05 ··· 0,3 mm	extra fine granules	0,3 ··· 2,0 mm

1. The technical and economical requirements of distribution equipment

The application of granules includes metering and distribution as evenly as possible over an area. Different grades of distribution need to be provided according to the types of granule, the area under treatment and other conditions (e.g. climatic).

Mineral fertilizers are distributed in relatively large amounts (which is why even with bigger particle-sizes, soil coverage is dense). Because of the concentration balance in the soil (especially when fertilizer is ploughed in) and high plant tolerance, no stringent requirements are demanded of the output accuracy of the machine and the evenness of distribution.

Using bigger particles (coarse granules) drift due to wind is very small and use of the economically favoured method of centrifugal distribution is possible.

Due to the high activity of plant protection materials, smaller amounts can be applied. Accurate output and distribution is, however, necessary to maintain activity and selectivity. This may be achieved by dispersion of the active ingredient in a liquid or by formulation on a solid inert material.

The handling of large amounts in bulk (storage, transport, filling and distribution) is not economical, so it is desirable to reduce the rate of application as far as possible without impairing activity. For the application of small amounts, small particle-sizes are necessary to achieve dense coverage (micro-distribution), with a lower limit of 100 to 150 µm as a precaution against drift.

Granular formulations of insecticides and soil acting herbicides were developed initially which were relatively coarse and could be applied with conventional distributors at rates of 30 to 100 kg/ha.

Later, granular formulations of foliar herbicides were developed, using micro-granules to ensure adequate retention by the leaves. The lower limit of size of granule is governed by the risk of drift. The rates of application for this type of treatment (5 - 15 kg/ha) are more economic than those used for the coarser granules of soil-acting herbicides, e.g. simazine, but a completely new method of application had to be developed for accurate distribution.

The economic use of such a system depends on its rate of working and time wasted, but accuracy must not be sacrificed for speed.

The amount of time wasted during application is influenced by the type of distributor used. Machines with containers extending over the whole width of work, will either cover too narrow a swathe (2.5 m), or be too complicated to handle (long drive- mechanism etc.).

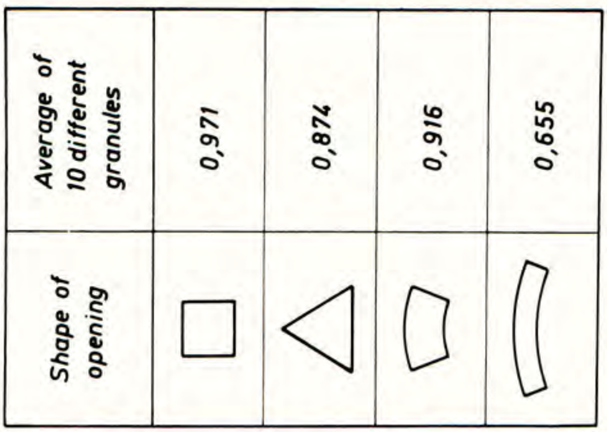
Those with central hoppers are easier to fill, while their extension arms can be folded or retracted for easier transport (especially by road).

2. Construction of the distributor

Normally time-constant metering is achieved by gravity feed through orifices in the floor of the hopper. The shape of the orifice has a great influence on the rate of output. Fig. 2 shows the variation in flow of various granules through different shaped orifices by comparison with a circular outlet.

Figure 2

Variation in relative flow rate of granules through various orifices



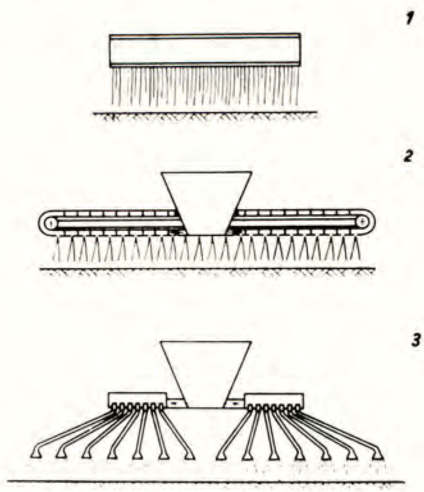
The effect of the varying level of material in the hopper on the rate of outflow can be eliminated by various means - 1. Mechanical: oscillating the container, agitating or scraper devices, 2. Pneumatic: excess pressure in the hopper and/or a floating bed.

Metering according to distance travelled requires forced delivery where the granules are volumetrically metered through toothed wheels, bucket wheels, bucket bands, screw conveyors etc. Determining factors for smooth function are the filling arc (bucket travel in hopper) and forced emptying of the buckets. The drive for the forced metering system comes from a ground wheel. For a system independent of terrain the tractor's power take-off can be employed.

At the Institute of Agricultural Engineering in Berlin, experiments on methods of metering are being conducted and will be published soon.

The overall evenness of any application is governed by both lateral and longitudinal distribution and different types of machine are the result of the combination of different metering and distribution systems.

2.1 Mechanical distribution systems (Fig. 3)



2.1.1 Machines with free outflow extending over the whole width of work and with a broad hopper. Material metered through a slit extending over the whole width. Similar type of distribution but for big amounts. Small working width.

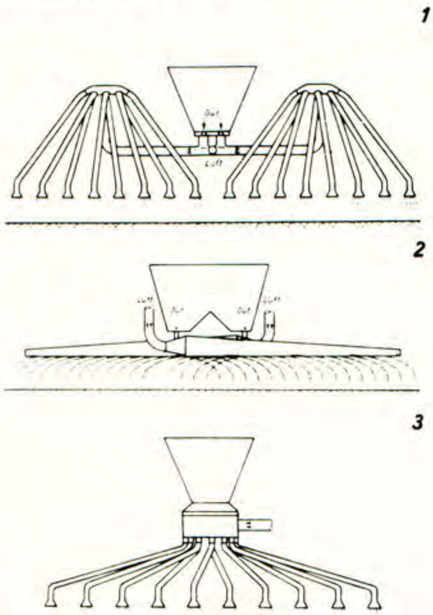
2.1.2 Machines with free outflow, central hopper and mechanical side conveyance, i.e. auger, conveyor. Central metering possible, therefore reduced amounts possible, expensive.

2.1.3 Machines with positive metering of part-streams and guided transport under gravity.

Volumetric metering and row deposition, secondary distribution possible through impact plates (broad-casting). With broad hoppers usual disadvantages. With central container side conveyance is necessary through channels of - as far as possible - equal lengths. Economically advantageous. Metering of reduced amounts possible. Good rate of side distribution. But not suitable for very small amounts and micro-granules. Limited width.

2.1.4 Machines with centrifugal distribution, free outflow and central container. Metering of small amounts through single orifices in hoppers possible. Distribution requires particles of definite minimum size (working width, danger of wind drift). Use is limited to fine granules. Not suitable for fine and extra fine granules even with wind protection.

2.2 <u>Pneumatic distribution systems</u> (Fig. 4)



The principles of metering are similar to those in 2.1; however the feeding of material into the air stream must take place either by suction or injection. The transport to the outlets takes place pneumatically in a 2-phase stream (material - air); similarly with the discharge. The optimum air-speed depends very much on the particle size spectrum and the specific gravity (settling speed) of the material.

The systems differ from each other through the combination of different methods of metering, material transport and nozzle outlet.

2.2.1 Machines dividing the 2-phase stream, Fig. 4, Nos. 1 and 2

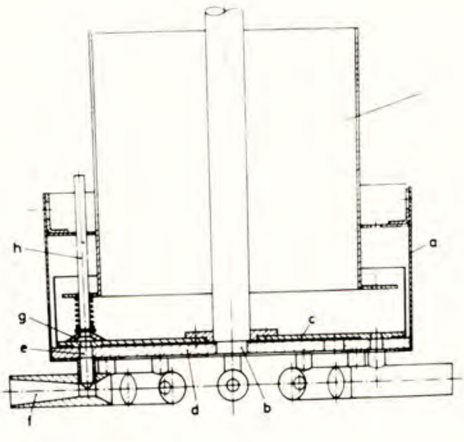
The release of granules into the air stream takes place centrally, mostly through a metering orifice in the floor of the central hopper (possibly two openings one for each of the air-streams) or through a bucket wheel. After the material has been uniformly distributed, the air stream plus material is divided between the individual discharge tubes. For mixing, corrugated tubes, or better still, a ring constricting the cross-sectional area are used. Partitioning takes place either by using compartments in the guiding channels and discharging through a slit in the floor of the channel, or the material/air stream mixture is divided into radially partitioned streams by a dividing head. Each single channel then leads to a separate outlet nozzle. Different channel lengths and locations cause, due to the different degrees of resistance, streams of different strengths, so that difficulties arise already at the primary distribution (in the single channels).

On the other hand with only one (possibly 2) openings for the whole working width, small outflow streams i.e. low rates of application, are possible.

2.2.2 Machines with partitioning of air streams and positive metering of the single material streams (Fig. 4, No. 3).

The material is positively metered into separate streams and delivered into the already divided individual air streams. It is thus possible to place nearly equal amounts of material into each channel even with differing air streams. The metering may take place by using special bucket wheels or augers etc., but with the large number of single streams, the amount per stream is very small. This requires small bucket volumes or a low delivery rate which should not be too low if pulsation of the material is to be avoided. A machine of this type with 12 metering rates, about 8 m working width, delivering 6 kg/ha at 2 m/sec, has been developed at the Institute of Agricultural Engineering, Berlin (Fig. 5).

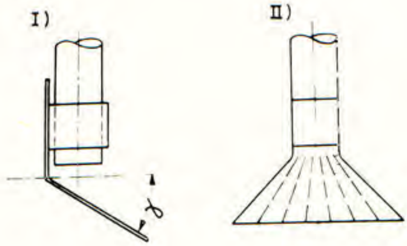
Figure 5



Key - a cylindrical housing
b pilot
c bucket plate
d bottom plate
e outlet
f injector
g covering plate
h tube
i insert

2.2.3 Individual nozzle outlets

Figure 6



The system of air channels provides the primary distribution of the material within the machine but the final distribution on the ground depends on the nozzle outlets. Their individual swathes must match up to give the overall swathe and their design also influences the amount of displacement due to wind which may occur.

Specification for individual outlets:

Stable under varying field conditions
Symetrical
Adequate overlapping to give even width distribution
Little pressure loss in the outlet nozzles

Distribution with impact plates results in circular segmented forms of distribution fields which have an included angle of (ϕ = 90° - 180°) and the resulting working width depends to a great extent on the plate inclination (y = 20° - 0°). Adequate overlap with sufficient working width (about 1 m) is produced by y = 20°. The particles, however, will be strongly retarded (reflected) especially at a small plate inclination, and thus susceptible to wind displacement. Plates are sensitive to side inclination and require homogenous mixing of the material in the air stream before discharge, otherwise unsymmetrical distribution will result.

With vertically arranged fish-tail nozzles, the 2-phase stream is split up by compartments in the nozzle. The homogenization of the material/air mixture is achieved by straight channel sections with a constriction. As a result of the high particle speeds and the short distances to deposition, the distribution of even small particles (0.1 mm) is insensitive to wind displacement, especially if the air speed at the outlets is equal to or more than 10 m/sec. The working width of each nozzle is in the range of 0.8 m with a standard deviation of o = 10%.

3. Methods to determine the standard of distribution

3.1 Investigation of metering behaviour

To take quick and accurate measurement readings, during investigations of metering efficiency, an electronic balance is used (inductive pick-up) the analogue values of which are recorded on an X-Y recorder or a UV-oscillograph. For further accurate mathematical processing of the values, the analogue signal can be converted by an analogue-digital converter and be shown at a counter and registered by a digital printer or a tape punch.

With the variation of this measurement system an ideal cumulative discharge function is given (by a function generator), and by this the differences between this ideal function, and the actual discharge function (balance value), the deviation with time can be continuously determined. The presentation takes place simultaneously on an X-Y recorder and in digits on a printer or tape punch.

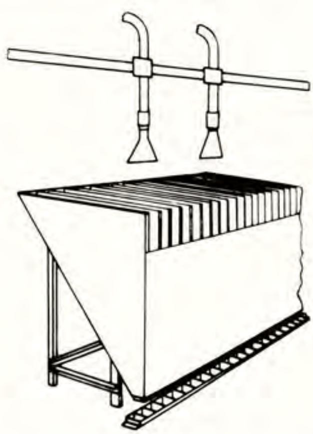
3.2 Determination of the accuracy of lateral distribution

For investigations on complete distribution machines (with large working width) a patternator, 16 m wide, 2 m long and with 10 cm divisions was constructed to support a driven tractor. To avoid possible bouncing of particles on the corrugated-metal sheet and for quick dissipation of the air stream of the pneumatic machine, the patternator was covered with a screen in the form of a cardboard grid having 5 x 5 cm divisions. A hydraulic tilting device for the individual patternator divisions makes possible the quick emptying into measuring vessels.

Measuring follows then with an electronic balance where the distribution curve is at once produced on an X-Y recorder and the single values are registered in digits for further mathematical processing. The calculations are carried out in a computer (ICT 1900) and include the evaluation of gradual overlapping of repeated and opposite journeys with determination of deviation and working width. Deviation values for each working width as well as the distribution pattern after overlapping are expressed diagramatically.

For accurate investigation of the individual distribution outlets (up to 3 pieces a unit) on the pneumatic machine, a special patternator was constructed (Fig. 7) to allow for the reduction of the usually high air speed. This was composed

Figure 7



of collection pits 1 m deep with 10 cm divisions, tilted back walls and a tightly closed floor flap. The distribution outlets which are attached over the patternator could be fixed in any desired position (height, distance, inclination). The measurement and calculation of the collected granule amounts was carried out as described above.

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DRY FORMULATIONS FOR SELECTIVE WEED CONTROL IN CEREALS

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Summary Dry formulations of herbicides using air as the diluent have distinct practical advantages particularly when water is in short supply. There are further advantages in the reduction of application time. The method of application together with retention and drift aspects are discussed. Field results over a number of years are described.

INTRODUCTION

Early work with 2,4-D and MCPA for selective broadleaved weed control in cereals led to the adoption and extensive commercial acceptance of low concentrate herbicidal dusts on a wide scale. Indeed even as late as 1956 seven herbicidal dust formulations appeared under the then Crop Protection Product Approvals Scheme, 1% and 2% MCPA materials predominating. Application was commonly made through the farm fertilizer distributor at rates up to 2 cwt/ac. Their use, however, dropped with the introduction of the more concentrated liquid formulations of MCPA and 2,4-D and the wide acceptance of low volume sprayers in the fifties.

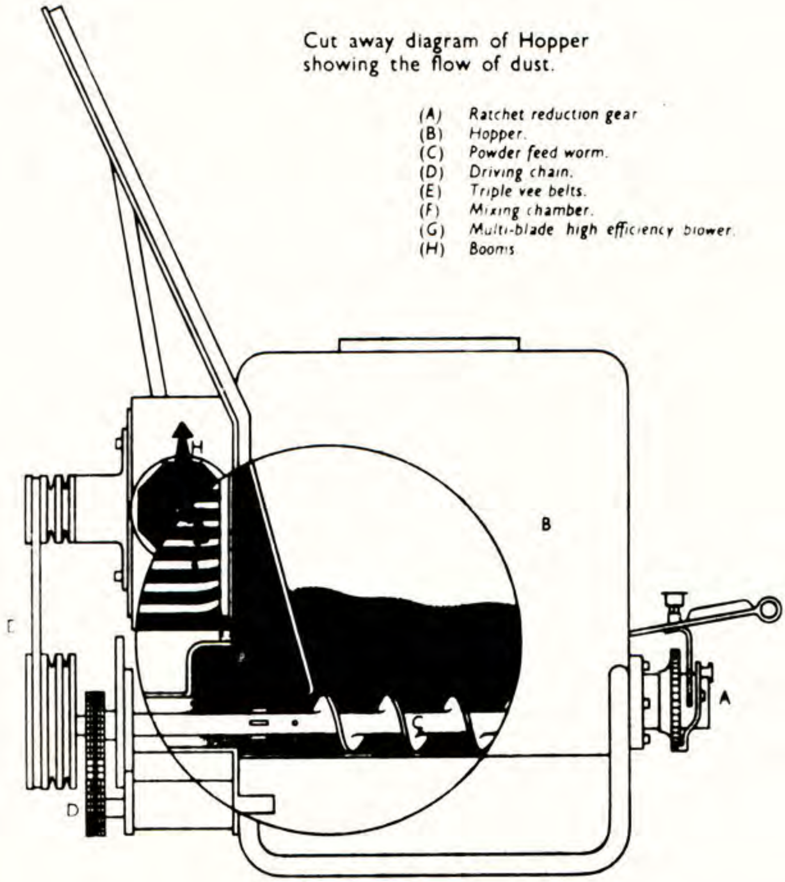
The introduction of the Chafer Dustmaster at the 1958 Smithfield Show as a quick and simple technique for applying high concentrate fungicidal and insecticidal dusts was followed by a preliminary observation trial in the spring of 1959 with a herbicidal dust. This material was manufactured using a conventional filler and although a plastic drift sheet was used along the Dustmaster booms photographs taken at this time show an unacceptably high level of drift. It was clear that if this method of application for herbicidal dusts was to prove viable the problem of drift would have to be resolved. This paper, therefore, gives an outline of the development programme with 'Granulox' as these micro-granules were termed and some of the problems encountered both from the application and herbicidal aspect.

MACHINERY

The Dustmaster as originally developed, primarily for the control of potato blight, consists of a weatherproof hopper with sloping sides for mounting on the three point linkage of the tractor. On either side of this hopper is a pair of tapered booms with outlets connected by flexible couplings to the fan casing at the rear of the hopper. A worm auger running in the bottom of the hopper feeds the chemical through an agitation chamber to an air inlet duct in the fan housing. The quantity of chemical applied per acre is a standard volume of 185 in^3 (7.5 l/ha) but because of the varying bulk density of different dusts the actual weight of material applied varies from 3 to 6 lb (1.36 to 2.72 kg), but mainly in the 5 to 6 lb (2.27 to 2.72 kg) range.

Cut away diagram of Hopper
showing the flow of dust.

(A) Ratchet reduction gear
(B) Hopper.
(C) Powder feed worm.
(D) Driving chain.
(E) Triple vee belts.
(F) Mixing chamber.
(G) Multi-blade high efficiency blower.
(H) Booms



By referring to the diagram it will be seen how the drive from the tractor p.t.o. shaft is taken from the agitation shaft running through the centre of the powder feed worm to the ratchet reduction gear. The powder feed worm turns at 1/50th the speed of the agitation shaft and operates in a series of regular movements. A patented multiblade blower is driven from the agitation shaft by pre-stretched triple vee belts, the air flow lifting and mixing the powder before it is fed to the booms. These booms generally have a 36 ft (11 m) working width with thirty one 1 in. (25.4 mm) diameter outlets at, usually, 14 in. (355.6 mm) centres. Individual outlets were fitted with a 9 in. (228.6 mm) flexible rubber pipe in which 1 in. diameter aluminium down pipes could be adjusted for height. With long and short pipes alternating effective cover was possible over fifteen potato rows.

The air pressure at the outlets initially was 1.125 foot water gauge (3,363 N/m^2) but in later models alternative pulleys increased this to from 1.85 - 2.0 foot water gauge (5,530 - 5,978 N/m^2). At the same time the diameter of the outlets was increased to 1.25 in. (31.75 mm) and a change made to plastic down pipes again adjustable for height within an outer rubber pipe. These had the advantage of improved wearing qualities in the field, particularly on uneven land. It will be appreciated that since the powder feed is positive and related to the engine and ground speed, the tractor throttle opening is relatively unimportant since the powder feed from the worm alters proportionately.

Very high work outputs are possible with the Dustmaster since the hopper contains sufficient powder to treat 50 acres (20 ha) of crop. With a working width of 36 ft (11 m), 403 yd (912 m) are travelled to cover an acre (hectare). Common working speeds are 5 m.p.h. (8 km/h), so in theory an acre (ha) may be treated in
2 2.8 min (6.8 min/ha). In practice work outputs in excess of 15 acre/h (6 ha/h) are commonly achieved.

During the winters of 1959 and 1960 development work was undertaken with alternative filling agents more suited for formulation as herbicides. This led to the adoption of certain grades of "Macrolite" as the diluent because of the very much lower drift factor. Different grades were prepared by sieving through 100, 200 and 300 mesh sieves but in these early days a much higher percentage of 'fines' was left compared with recent formulations which only contain a maximum of 3% wt/wt.

In the course of this development work boom design and positioning were found to be critical as otherwise there was considerable variation in the output of herbicidal dust firstly to the individual booms and secondly between nozzles. There was also a tendency for nozzle output to be high towards the ends of the booms again due to the necessary change in filling agent. Nozzle outputs were established at different p.t.o. speeds initially by collecting the powder in stockings and then weighing. Later it was found that the restriction in airflow could influence the distribution of herbicidal dust and nozzle output was then found by catching in water containers and weighing after each series of tests. Preliminary trials showed that output from individual nozzles varied as much as 150%. At this stage in the development programme an additional restriction was fitted round the feeding worm to even up the flow of herbicidal dust. A removable trap was also fitted after the restriction so that the machine could be calibrated for different settings.

In order to get the powder distributed as evenly as possible experiments continued with different booms. These included tests with individual booms, booms fitted with adjustable slots, experiments with drilled plates at the flexible joint and variously positioned deflectors. It was not possible to correlate the powder output from nozzles with the air pressure and it was subsequently established that design of the flexible hose and joints in the boom itself also affected output. At this time some trials were made with fibre glass booms but these were not sufficiently strong to withstand field use. The outcome of these machinery development trials was a return to metal booms but fitted with adjustable impact plates at each nozzle outlet. Alternate outlets were angled backwards and forwards so that these impact plates were able to catch the herbicidal dust. The amount the impact plates should protrude into the airflow was determined as previously and it was, therefore, possible to build individual machines with consistent nozzle output.

A number of prototype Dustmasters were produced in the autumn of 1965, mainly for the Argentine, in which a new design was tested. With these Series II machines the worm was driven at right angles to the p.t.o. shaft via a belt drive and reduction gearbox. The main advantage of this machine was that the powder was fed from both ends of a 2 in. (50.8 mm) diameter worm directly into the airflow. Breakdown of the Granulox by the fan was thus avoided and it was also possible to alter the speed of the worm as the belt ran on variable pulleys. With this Dustmaster the design of the worm since it actually worked in the airflow was found to be critical, as breaks in the powder feed could otherwise be caused.

During 1967 an entirely fresh approach to Granulox application was made. Basically the herbicidal dust and air was fed into the bottom of a funnel shaped tube machined with circumferential ridges. Since this tube tapered from 4 in. (101.6 mm) to 3.5 in. (88.9 mm) the air and herbicidal dust were completely mixed and carried upwards towards an 18 in. (457.2 mm) diameter plate with 25 outlets round the outside. The powder was then split off towards these outlets by a central cone and led along the boom by individual 1.25 in. (31.75 mm) flexible reinforced plastic pipes. As the position of the central cone was adjustable ±5% variation at the outlets was possible. With this applicator the boom width was reduced to 32 ft (9.75 m) thus conforming with the majority of the firm's sprayers, the individual outlets on the 2 in. (50.8 mm) diameter boom thus being slightly wider at 15.5 in. (393.7 mm). No problems have been encountered with the different lengths of the individual pipes and provided awkward loops were avoided consistent and even output was achieved. Boom height was readily adjustable on a parallelogram structure so that individual adjustment of the outlets was unnecessary.

DRIFT ASPECTS

Early field work had shown that herbicidal drift could be a problem and so whilst the application machinery was being developed drift trials were undertaken. Information was obtained using indicator plants, usually rape or tomato plants, grown in pots and which were placed at intervals along the proposed boom width and at varying distances from the end of the boom. The Dustmaster was then run at the normal speed over or at right angles to the plants. This work was repeated under different wind strengths. An alternative approach was to note the deposit of different "Macrolite" grades on gummed strips of paper. Although this technique provided useful comparative data it was probably not as critical as the use of indicator plants for low amounts of herbicide.

Further drift trials were conducted in 1964 in Germany by the Pflanzenschutzämter at Hanover, Munich and Kiel. Again rape plants were grown in pots and placed at 1 m intervals and up to 50 m away from the swathe. Plants were also raised up to 1.5 m. General conclusions were that drift was satisfactory under the conditions tested in winds of 4 - 6 m.p.h. (6.4 - 9.7 km/h). Similar drift trials with a Granulox formulation including picloram were completed in early 1967. PVC cups each with 2 Minor tick bean and 2 Dark Skinned Perfection pea plants were set out on level ground at right angles to the machinery run and at 1, 2, 4, 8, 16, 32 and 64 yd (0.9 m, 1.8 m, 3.7 m, 7.3 m, 14.6 m, 29.3 m, 58.5 m) from the end of the boom. Additional plants were raised up to 3 ft (0.9 m) for the 32 yd and 64 yd positions. After application the plants were collected and placed under a growth light. A light spray of water was given to encourage the absorption of the herbicide and assessment of any herbicidal effect made after 5 and 7 days. Under the conditions of application with wind speeds of 3 - 5 m.p.h. (4.8 - 8.0 km/h) most plants originally 2 yd (1.8 m) from the end of the boom developed damage symptoms but only 50% of those 4 yd (3.7 m) away produced any symptoms and these were only slight. Plants 8 - 64 yd (7.3 - 58.5 m) away did not show any signs of herbicidal damage.

METHODS AND MATERIALS

Trials procedure in individual years was greatly influenced by the type of application machinery and in the early years particularly the emphasis was towards a large number of non-replicated reliability trials. It was thus possible to reduce the problem of a slight delay in the powder feed which would have featured with small plots which could have meant the machine was not working at the desired application rate. Scope and methods for trials and materials used are recorded by year.

Table 1

1960 Treatments

		Active ingredient in acid equivalent	The coded herbicidal dust formulation
SWK	1	13.3 oz of mixed 2,4-D/MCPA esters (0.93 kg/ha)	4.6 lb/acre (5.15 kg/ha)
SWK	2	6.5 oz 2,4-D and 14 oz mecoprop esters (0.45 kg and 0.98 kg/ha)	5.9 lb/acre (6.60 kg/ha)
SWK	3	7.4 oz 2,4-D and 9.6 oz mecoprop esters (0.52 kg and 0.67 kg/ha)	4.8 lb/acre (5.37 kg/ha)

The treatments in Table 1 were applied to a total of 81 fields in England and Scotland, the weed spectrum dictating the choice of material used. Plots were a minimum of two 36 ft (11 m) strips across the field and double rates of both herbicide and filler were applied to check on the effect of increased cover and weight of materials applied. Untreated control plots were left in all cases. The relevant meteorological data, especially wind speed and temperature, were recorded at application and afterwards. The number, height and vigour of individual weed species in fixed quadrats were recorded before application and at intervals through to harvest. Observations on weed control by standard herbicides applied to the rest of the field were also made.

Table 2

1964 Treatments

	Active ingredient in acid equivalent	Dust formulation
A	5.75 oz MCPA and 10.9 oz 2,4-D (0.40 kg and 0.76 kg/ha)	5.9 lb/acre (6.60 kg/ha)
B_1	32 oz dichlorprop and 9 oz 2,4-D (2.26 kg and 0.56 kg/ha)	12.0 lb/acre (13.44 kg/ha)
B_2	30 oz dichlorprop and 9 oz MCPA (2.10 kg and 0.63 kg/ha)	12.0 lb/acre (13.44 kg/ha)
C	18 oz 2,4-DB and 9 oz MCPA (1.26 kg and 0.63 kg/ha)	11.1 lb/acre (12.43 kg/ha)

Four formulations were manufactured, the Granulox A being a development of the original SWK 1, a mixed ester formulation of MCPA and 2,4-D being available.

Fifty two trials were laid down in the main agricultural areas of England, the emphasis being with the formulation B_1 and B_2. Again large plots were used and a similar method for recording weed control using fixed quadrats. With trials in previous years alterations in the weight of herbicidal dust per acre (hectare) were not possible. In this season however a development applicator was used for trials with a powder feed worm driven hydraulically. It was, therefore, possible to test the B_1, B_2 and C formulations at ¾, 1¼, 1½ and twice the standard application rates given above. Again control plots were left and the weed control given by the standard farm spraying was noted. In several trials it was possible to also include a standard herbicide treatment in water.

Table 3

1965 Treatments

	Active ingredient in acid equivalent	Dust formulation
65/1	24 oz mecoprop and 0.375 oz picloram (1.68 kg and 0.026 kg/ha)	9.0 lb/acre (10.07 kg/ha)
65/2	24 oz mecoprop and 0.75 oz picloram (1.68 kg and 0.052 kg/ha)	9.0 lb/acre (10.07 kg/ha)
65/3	5.75 oz MCPA, 10.9 oz 2,4-D and 0.75 oz picloram (0.40 kg and 0.76 kg and 0.052 kg/ha)	5.9 lb/acre (6.60 kg/ha)
65/4	5.75 oz MCPA, 10.9 oz 2,4-D and 1.5 oz picloram (0.40 kg and 0.76 kg and 0.105 kg/ha)	5.9 lb/acre (6.60 kg/ha)
65/5	30 oz dichlorprop and 0.375 oz picloram (2.10 kg and 0.026 kg/ha)	9.0 lb/acre (10.07 kg/ha)
65/6	30 oz dichlorprop and 0.75 oz picloram (2.10 kg and 0.052 kg/ha)	9.0 lb/acre (10.07 kg/ha)

A number of trials were completed in the Argentine with an associate company using low rates of 2,4-D esters to conform with local experience, but the main effort in the United Kingdom was with herbicidal dust formulations that included picloram at different levels.

The Dustmaster with hydraulic drive was again used this year, the main improvement for trials purposes was the use of booms 18 ft (5.5 m) wide. It was thus possible to use comparison plots 100 ft - 200 ft (30.5 - 61 m) long and 18 ft (5.5 m) wide and as well as being more convenient the extent of any possible soil residues was minimised. A standard herbicide treatment and untreated control plots were included in all trials as previously. In this year 8 such trials were completed on winter wheat, 1 on winter barley and 6 on spring barley.

Table 4

1966 Treatments

	Active ingredient in acid equivalent	Volume of liquid or dust applied
66/1	22.4 oz MCPA/acre (1.57 kg/ha)	50 gal water/acre (562 l/ha
66/2	35.7 oz dichlorprop and 0.375 oz picloram (2.50 kg and 0.026 kg/ha)	50 gal water/acre (562 l/ha)
66/3	5.75 oz MCPA and 10.9 oz 2,4-D (0.40 kg and 0.76 kg/ha)	5.9 lb/acre (6.6 kg/ha)
66/4	11.5 oz MCPA and 21.8 oz 2,4-D (0.80 kg and 1.52 kg/ha)	11.8 lb/acre (13.2 kg/ha)
66/5	17.25 oz MCPA and 32.7 oz 2,4-D (1.20 kg and 2.29 kg/ha)	17.7 lb/acre (19.8 kg/ha)
66/6	treatment 66/3 and 0.375 oz picloram (0.026 kg/ha)	5.9 lb/acre (6.6 kg/ha)
66/7	treatment 66/4 and 0.75 oz picloram (0.052 kg/ha)	11.8 lb/acre (13.2 kg/ha)
66/8	treatment 66/5 and 1.125 oz picloram (0.078 kg/ha)	17.7 lb/acre. (19.8 kg/ha)

Although the results in 1965 showed considerable promise, residues with picloram particularly in dry seasons were found. In effect this limited the application rate of picloram to 0.375 oz/acre (0.026 kg/ha). Accordingly the 1964 'A' formulation was tested with and without 0.375 oz/acre (0.026 kg/ha) picloram using crop yield as the criterion for toxicity. Nine trials, three on spring barley, three on spring wheat, one on winter barley and two on winter wheat were completed. A randomised block layout with four replicates of the ten treatments was used.

Plots were 18 ft (5.5 m) wide and such a length that using the farm combine the area harvested was 1/40 acre (100 m^2). Although relatively weed free the weed control given by the different treatments was noted and in addition a further 15 weed control sites were laid out in England and Scotland. In some of these trials it was possible to include a 36 oz (2.24 kg) mecoprop, 1.5 oz (0.105 kg) dicamba formulation, application rate 15 lb/acre (16.8 kg/ha) and a 24 oz (1.68 kg) dichlorprop, 6 oz (0.42 kg) 2,4-D, 4 oz (0.28 kg) ioxynil ester formulation for application at 11 lb/acre (12.3 kg/ha). The weed control after three weeks and at harvest was recorded as a percentage together with the percentage ground cover. An analysis of results was made listing individual weeds as S, MS, MR and R in the seedling and young plant stages.

Table 5

1967 Treatments

	Active ingredient in acid equivalent	Dust formulation
67/1	36 oz mecoprop and 1.5 oz dicamba (2.5 kg and 0.105 kg/ha)	10.6 lb/acre (11.9 kg/ha)
67/2	5.75 oz MCPA, 10.9 oz 2,4-D and 1.5 oz dicamba (0.40 kg and 0.76 kg and 0.105 kg/ha)	5.9 lb/acre (6.6 kg/ha)

At this stage picloram was no longer available in the United Kingdom and so two formulations based on dicamba were included in trials.

In previous years ester formulations had been used but it was possible to reduce the weight of filler to absorb the mecoprop by dissolving the technical acid in the ester. Nine weed control trials with plots 18 ft (5.5 m) by 200 ft (61 m) on winter wheat variety Capelle, winter barley - Dea, spring wheat - Kloka and spring barley - Zephyr were completed. Unsprayed control plots were included as well as a standard herbicide treatment at 40 gal/acre (449 l/ha). In a number of trials the retention aspect of Granulox was tested by pre-spraying water at 4 - 5 gal/acre (45 - 56 l/ha) immediately before application. Again the percentage ground cover, height, number and weed control were recorded.

1968 Treatments

Application problems had influenced weed control in previous years and since retention of the herbicidal dust influenced results it was decided to re-examine the formulation 67/1 (Table 5) and B_1 (Table 2) using the new applicator. Twelve weed control trials were completed on winter and spring wheat varieties Zephyr, Deba Abed, Proctor, Vada, Capelle and Kloka. Plot size had to be increased because of the 32 ft (9.7 m) width of the improved applicator and in general these were a single pass across the field. Unsprayed controls were left but it was not practical to include a comparison herbicide. Weed control was recorded both by the percentage ground cover and on a scale 0 - 10.

RESULTS AND DISCUSSION

The earlier work in 1959 and 1960 showed that a reasonable degree of control of the more susceptible weeds was possible using the MCPA/2,4-D formulation. This was particularly so when applied on the lighter soil types to weeds in the seedling stage. Trials also showed that 100 - 200 mesh materials were most suitable from the drift aspect but in the early stage some manufacturing problems were found in making a herbicide with an acceptably low percentage of fines.

In 1964 it was found that 26 in (660 mm) ground clearance from the bottom of a 9 in (229 mm) long rubber outlet gave a reasonably even distribution along the swathe in winds up to 10 m.p.h. (16.1 km/h) without an excessive drift problem. However, some variation in weed control of the more resistant weeds was noted. In two trials in 15 - 16 m.p.h. (24 - 26 km/h) winds, plastic down pipes were used to give 12 - 13 in (305 - 330 mm) clearance. Although drift was avoided, marked striping of the material was observed and there was also a tendency for the herbicide to be carried past weeds such as black bindweed with a shiny leaf surface. The B_1 formulation again gave a control of the more susceptible weeds but the control of chickweed and cleavers was poor. The B_2 formulation generally was not as effective as B_1 and hempnettle was not adequately controlled. At this juncture it was clear that development of a "Granulox" for chickweed and cleaver control should take priority and work with a 2,4-DB/MCPA formulation was not continued.

1965 saw considerably improved weed control by the inclusion of picloram in the formulations 65/1 - 65/6. These trials were on sites where cleavers (Gallium aparine) and chickweed (Stellaria media) were the main weeds. Broad conclusions were that picloram at 0.75 oz/acre (0.052 kg/ha) gave a good control of cleavers, particularly with the dichlorprop formulation. Chickweed control was very similar with both the mecoprop and dichlorprop formulations. Good control of the black bindweed (Polygonum convolvulus), redshank (P. persicaria), mayweed spp. (Matricaria spp.) and knotgrass (P. aviculare) was noted. Some unevenness in application was recorded. Unfortunately the residue position with picloram meant that only 0.375 oz/acre was possible and for this reason formulation 'A' with this lower rate was prepared for the following season.

The 1966 yield results showed no significant effects on yield with both the formulations tested even at three times the recommended rate. The straw of spring wheat variety Opal was shortened in one trial and a whitening effect on barley Ruby was noted but this did not produce significant yield effects. Weed control results confirmed the improvement by the inclusion of picloram, especially on the Polygonaceae, and although not expected, an improved control of seedling chickweed. Some variation in application was again noted on weedy sites and improved weed control where crops were moist at application due to persistent heavy dew. In one trial applied under winds of 15 m.p.h. (26 km/h) poor retention of the herbicide on black bindweed was noted. However, uptake from the soil of the picloram controlled this weed. On fen soils weed control was disappointing probably due to the combined effects of vigorous weeds and the herbicide being absorbed on this soil type. The limited work with formulation 66/1 showed this to be a promising material on mineral soils with an improved control of chickweed, a severe check to cleavers but not as effective as the picloram formulation on black bindweed. Weed control was not satisfactory on fen soils.

1967 was generally a difficult spraying season and in practice it was found that crops were either relatively wet until well into the afternoon or conversely later on in the season so hot and dry that the pre-sprayed water tended to evaporate before the "Granulox" could be applied. It was clear that application was a limiting factor for the evenness of weed control and that moisture present in well grown crops led to an improved control. In some trials pre-spraying with water improved the weed control but not significantly so. The lower application rate for the mecoprop/dicamba formulation possibly also influenced results because of reduced cover.

In 1968 large plots had to be used and so there were the problems of a varying weed spectrum and some changes in soil type for different plots. Nevertheless an improvement in overall weed control confirmed the value of a more even cover from the new applicator. Weather conditions varied considerably during these trials. Initially they were cold and wet, then followed a period of showery weather with low night temperatures and eventually normal good spraying conditions. It was, therefore, interesting to record that the best results were obtained with the early trials, the converse to normal wet spraying. This confirmed the observations in weed control in previous seasons that retention and evenness of cover had a marked effect on the final result.

The high work output possible with dry formulations of herbicides has been confirmed over several years both in limited commercial usage and in extensive reliability trials. Adequate moisture within the crop was necessary for a high standard of weed control and the importance of soil uptake of herbicide was shown in several trials. Concurrent developments with machinery for the application of fertilisers in solution have more recently been given priority. It is also noteworthy that in recent months herbicides have been coming onto the market as dry formulations, in the form of concentrated soluble powders.

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THE METERING AND DISPENSING OF GRANULES AND LIQUID CONCENTRATES

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INTRODUCTION

The present generation of sprayers and granule distributors are mechanically simple and robust. They do, however, demand considerable driving skill and concentration on the part of the tractor driver. The increasing use of crop protection chemicals and liquid fertilizers spread over a much longer season each year requires that much of this work is performed when the going is poor. Quite small variations in soil conditions and slope can result in noticeable changes in tractor speed. The time has come when systems devised to reduce this and other types of error should be considered. Developments occurring outside the agricultural industry may eventually be found adaptable to these needs.

METERING OF LIQUIDS

It is perhaps one of the strangest features of agricultural sprayers, that they attempt to perform the metering operation and the dispensing operation by one and the same device. Liquid is fed to the nozzle orifice at constant pressure and this ensures accurate metering with time. The same orifice is ingeniously constructed to give rise to a rudimentary dispensing or distribution of the liquid within the crop being treated. It has been thus for almost a century. Simplicity of design, such as this, is a great virtue but it does lead to a certain complexity of usage.

When applying a chemical to a crop, we are not really interested in metering it at a rate constant with time. If we use this method we have to maintain a constant speed as well, in order to obtain an application rate constant with distance. Herein lies the major error in all spraying. Outside the field of agriculture, there is a major application problem where speed has to be variable. Ironically, this is on British Railways where wheelslip is minimal and the sprayer is at all times moving on a perfect track, but speeds are liable to vary between 0 and 50 mile/h (80 km/h).

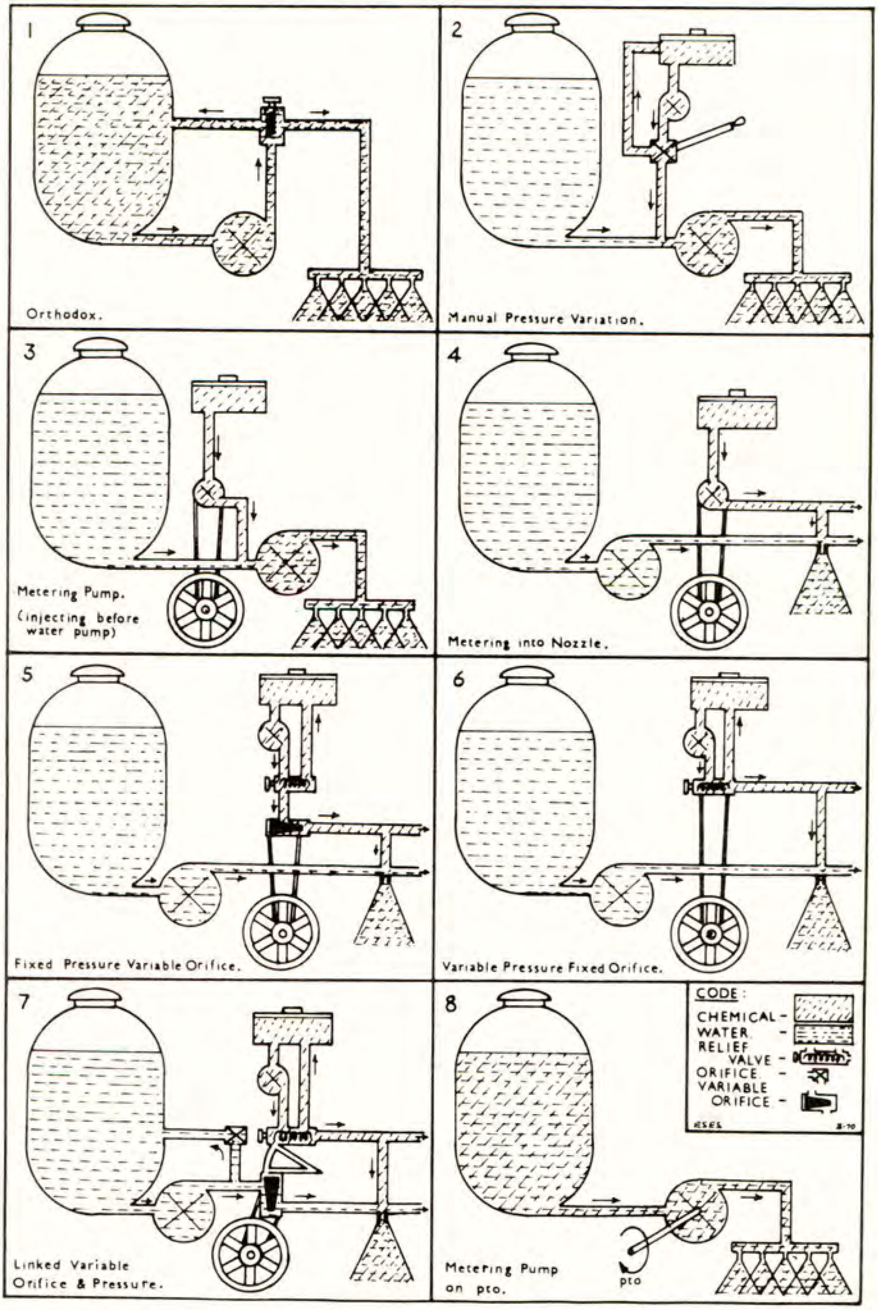
Figure 1 shows, diagrammatically, the basic agricultural sprayer as we know it today - water and chemical mixed together and pumped through a pressure regulator or relief valve to the nozzles (constant pressure, fixed orifice, constant speed).

Figure 2 illustrates a system which was used in the early days of spraying; chemical concentrate is pumped through a manually variable orifice into the intake of a pump supplying water to the nozzles (chemical pressure is varied according to speed using a speedometer marked with the appropriate pressure, fixed orifice, water constant with time).

The third (Fig. 3) is a more sophisticated system using a metering pump driven by a land wheel to inject chemical into the water-stream, again mixing in the main pump (chemical constant with distance, water constant with time). The latter two systems have the serious disadvantage that there is a delay between the arrival of chemical at the point of injection and the moment when it is emitted from the nozzles. This time lag produces an appreciable error every time there is a change of speed. This is overcome in the fourth system (Fig. 4) by injection of the

Figures 1 - 8

Diagrammatic arrangements of liquid flow and control systems for sprayers



chemical concentrate at the nozzles. Really reliable metering pumps that will cope with highly concentrated chemicals are liable to be expensive. On one railway sprayer, the metering pumps made of stainless steel would cost £2,000 today and their total weight amounted to one ton.

Figure 5 shows one way in which the metering pump might be side-stepped using a variable orifice controlled by a land wheel to meter chemical supplied at constant pressure for injection at the nozzle (constant pressure, variable orifice). From an engineering point of view this is not as simple as it seems.

A more satisfactory alternative would be the one shown in Figure 6 - a pressure variator controlled by a land wheel (variable pressure, fixed orifice). A series of interchangeable fixed orifices would permit use of alternative dosage rates.

Probably the most sophisticated idea would be the seventh arrangement (Fig. 7) where the variable orifice controlled by a land wheel is linked mechanically to a pressure variator on the water supply. A range of permutations of this method with various servo systems can be envisaged. It is fairly easy to think up variations on these themes and on paper these ideas may appear unnecessarily complex for agricultural purposes, but if true genius is shown by designers and engineers in their physical embodiment of a sophisticated idea it can result in a mechanically simple, robust and reliable device. At this stage, one may well ask "why not, for agricultural purposes, make use of a simple metering pump driven by the tractor p.t.o., at a speed having direct relationship to tractor speed"? Unfortunately, wheel slip on soft ground or uphill work would cause a speed up of the metering pump at the same time as a slowing down of the sprayer resulting in overdosing, and vice versa. Such a device is illustrated in Fig. 8. This system also suffers from a gross variation in drop size owing to the large pressure changes with slight alterations in speed.

Basically, patented arrangements employing these last seven systems either rely on a fixed orifice and variable pressure, a fixed pressure with variable orifice, or a combination of the two. The main lesson to be learnt from studying these devices is that the chemical should be metered separately from the diluent, and the metering device must be operated by a trailed and not a driving wheel - normally this requires interposing some type of simple servo-mechanism.

Any attempt to meter the <u>diluted</u> chemical relative to distance, results in gross pressure changes, and thus, variable drop size. This is less likely to be tolerated in the field than a system of metering a variable amount of chemical into a steady water stream, which results in some variation in concentration. There are some complications, but they are minor ones. Change of dilution means change of surface tension which in turn would entail variation in drop size (but much less so than if the pressure were changed). The concentrate would have to be injected into the water stream at each nozzle and not at the point of entry of the water into the spraybar - the latter would result in excessive delay before a change in concentration reached the more remote nozzles.

We are not here concerned with metering or dilution of materials logarithmically. As an experimental spraying technique it is of long standing and well documented, but it is unlikely to find a use in commercial agriculture. But if metering and dispensing can be completely divorced there may be an increase in the development of new methods of dispensing. Some success has been achieved already in the various rotary atomisers where the fluid is metered through a fixed orifice and is then fed into an entirely independent dispenser. The increased mechanical complexity is, in many cases, justifiable especially where it can be shown that close control of drop size is required, as in the case of waterless spraying.

DISPENSING OF LIQUIDS

The perfect means of dispensing a liquid on a crop has yet to be devised. But very reasonable compromises have been attained and are readily available at moderate prices. Hydraulic nozzles conforming to British Standard 2698 can now be obtained. But for years we have been regarding the required quantitative distribution as being trapezoidal or triangular. In the latter years the position has become clearer and it is usual to recommend trapezoidal patterns for public health use and post-emergence band spraying, using only triangular patterns for boom sprayers.

More recetnly Hartley (1968) has shown that the triangular distribution is in reality an over-simplification of the desired pattern. For boom sprayers, nozzles with a Gaussian or "normal" distribution should be found. These can be shown to be less susceptible to variation in boom height. With a true Gaussian distribution it is only necessary to know the distance between nozzles in terms of the Standard Deviation to determine the variation in volume deposited across the swath for that nozzle spacing. It might be an intriguing exercise in semantics, to devise a satisfactory British Standard along these lines. Many nozzles which conform to the British Standard Triangular distribution do, in fact, approximate to the Gaussian form and this is undoubtedly advantageous.

METERING OF GRANULES

There is here a problem in that the active ingredient and diluent are fairly securely attached to each other by the manufacturer of the product. Therefore, if the material is metered through a fixed orifice in the time-hallowed hour-glass fashion, either the distributor must travel at a precisely constant speed or else the orifice must be controlled by the speed of a land-wheel. For free flow through a metering orifice, the minor dimension of the orifice must be greater than about six times the diameter of the granules. This tends to limit the lowest reliable output of such distributors. So, rather than use a multiplicity of metering points, attempts have been made to use a single large metering device capable of dealing with a wide range of products, then by simple physical means such as a rotating airstream or riffle device to split the metered supply into aliquots to be fed to a number of outlets.

The most successful granule distributors are, therefore, designed as volumetric "granule metering pumps", using augers or toothed drums. The principal difficulty here is possible incompatibility between the metering device and the granular product. The product literally has to be tailored to suit the applicator, otherwise the machine may act as a very efficient grinder or compressor of granules. Unfortunately, the formulation chemists' preferred end product may vary from dense, non-absorbent, stome chips to light porous minerals or odd waste products such as ground corn cobs. To design one dispenser that can deal with such a wide range of materials is enough to tax the ingenuity of the best engineer. For all purposes, a granular material free from fines or dust (i.e. narrow cut) is essential to ensure free flow of the product down a hopper and through the metering device. The bulk density of a granular product has been shown by Harwood and Pilpel (1969) to be the parameter controlling its rate of flow through an orifice. To assist in calibration the bulk density and flow rate (which are closely related) of all granular products needs to be published on their containers and accompanying literature.

DISPENSING OF GRANULES

Biologists may require granules to be:

1. Broadcast so as to lodge in the axils of leaves.
2. Broadcast on the soil surface.
3. Broadcast and mixed in a certain depth of soil.
4. Placed around the base if individual plants.
5. Placed in a band on the soil.
6. Placed in a thin line on the soil.
7. Placed in a line just under the soil, but above the seed.
8. Placed in a line just below the seed.
9. Mixed with the soil surrounding the seed.

Again, to design one machine which can perform all these functions is a challenge to any engineer, and it is to be hoped that biologists will not add to the list.

Broadcasting from aircraft is relatively simple and an economic proposition. Swath widths as great as 30 yd (27 m) can be achieved. Rather narrower swaths are produced by tractor-mounted spinning distributors. But if the product is to be flung out over a wide swath, the granules must have a high individual mass, which tends to be incompatible with the usual biological requirements of a large number of granules per unit mass of product.

Where granules are to be metered down a series of tubes to individual outlets or blown along tubes, a larger number of small but individually lightweight granules might well be preferred. The aerodynamics of the transport of granules through such systems is undoubtedly complex and the sooner we are able to inform formulation chemists of the physical specification required of our granules the better. The biologist can see fairly clearly what he wants to do with granules. The engineer can see several ways of metering the granules, but the problem of dispensing the material to the place where the biologist wants it is still wide open to study. Until this aspect is clarified, the formulator of granules is to some extent working in the dark.

One point which is frequently not appreciated by the engineer, formulator or biologist, is that wherever granules are broadcast, their distribution in the field can be no better than the surface they fall upon. If the axils of the leaves of the crops are incapable of retaining granules, the granules cannot be expected to lodge there. If a perfectly random distribution of granules is placed on cloddy soil, the granules will immediately roll down into crevices and become far from randon in their distribution. If they are then worked into a poor seed bed a relatively poor distribution is more likely to result.

Finally, work done by Atkinson et al (1968) in Australia shows that (as for liquids) we require a Gaussian distribution of seed or granules from broadcast equipment. This makes overlapping of swaths less critical (which is helpful to aerial operators). Lee and Stevenson (1969) have suggested that the disc type distributor should be replaced by two lateral high speed spinning drums to produce a very wide swath and the central peak should be filled in with a simpler distributor. Brazelton (1969) has shown that when orthodox spinners are used on aircraft a 20% improvement in distribution can be achieved by the simple process of flying "round robins" instead of "progressive passes". This idea does, unfortunately impose additional expenditure on swath markers. Presumably to produce a Gaussian distribution of granules from a point source, a random distribution of granule mass is required. This is only compatible with the requirement of a "narrow cut", if we envisage a random distribution of densities.

Razak (1969) has called for the institution of a single parameter to express the symmetry of distribution of fertilizers or granules.

CONCLUSION

After about 85 years use in agriculture of conventional metering in conjunction with the dispensing of liquids and from a relatively few seasons experience of applying granules, the lack of logic in our well established methods is beginning to become apparent. There is scope for much improvement still. It is an interesting surmise as to what extra economies in dosage rate could be attained by improved accuracy of metering and dispensing. There must be a point where extra accuracy becomes of no further economic gain. To go further than realism necessitates would be wasteful of effort. Our objective should be the maintenance of adequate metering and dispensing with a minimal opportunity for error resulting from lack of experience or attention by the operator.

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AN ASSESSMENT OF CURRENT RESEARCH AND DEVELOPMENT EFFORT IN PESTICIDE APPLICATION

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This Symposium has provided the forum for discussion of the current research and development effort on application and, as such, any assessment must be largely a catalogue of the papers presented. Clearly this is pointless, for the papers have been distributed, and are published in this monograph. Rather then, this paper attempts to highlight the gaps in the subject as revealed by this Symposium and to comment on some aspects of the work in hand.

Application is a wide subject, and there is perhaps a need to try and define more precisely what is covered by this vital subject. The author attempted this some time ago (Norman, 1965) but it has to be acknowledged that there is as yet no clear definition forthcoming. Perhaps this is one cause of the papers today often avoiding the consideration of the effect of a specific part on the whole operation.

Examination of the papers presented would suggest that there is a lack of fundamental research into this subject. This is in no way to decry the excellent work of the various Agricultural Research Council (A.R.C.) and similar units, but rather to ask where are the academic researchers into this subject? It has been abundantly demonstrated that workers in this field are conscious of the need to develop techniques which permit research into application methods and allow the scientific assessment of developments which have, or are, taking place. Some attempt has been made (see Frick, p. 23) to relate cover to disease control, and there are valuable contributions to the practical field use of the equipment available. But the question posed must relate to the fundamental point, namely are the present application techniques those which permit the optimum control of pests (and diseases etc.) with the optimum dose of chemical and minimum environmental problems?

There can be little doubt that present application methods do show an adequate result but is this perhaps related to the current screening methods in the industry? Do these in fact only bring forward materials which allow considerable latitude in application and consequently application methods are not so critical as maybe theoretically indicated?

These two factors, screening and field application, are related and perhaps it is here where some fundamental academic work is required. There is, of course, some work on pesticide residues and similar studies, but of all sciences, pesticides and their application would appear to meet most fully the Science Research Council's (S.R.C.) objective, "the creation of scientific and technological assets through the training of highly skilled manpower and through the support of research whose timeliness and promise is likely to lead to the discovery of new knowledge and techniques of significant scientific, social and economic benefit" (S.R.C., 1969).

The nature of the work which might be carried out by S.R.C. sponsored bodies is somewhat different to that of A.R.C., and equally it is unlikely to duplicate the work in industrial concerns. The type of study suggested by Joyce (see p. 76) in which 'national' control of a single pest species might be more economic, and biologically more effective, is something which only a "non-committed" body could undertake. It is in this area of broad "pest control" that the real impact of such work can be anticipated.

On the other hand there are the A.R.C. institutions which have shown by their many and varied contributions to this Symposium that a tremendous amount of useful work is being done. It is however for examination as to the extra cost of the work which arises from it being carried out in scattered locations; the liaison between the various units is clearly good, but the time involved must be substantial. Perhaps the time has come for a re-examination of A.R.C. activities in this field, and the B.C.P.C. might well be the body to make some suggestions of the future role of the various institutions. Clearly a re-appraisal is required and the establishment of a multi-discipline application unit based on one of the existing institutions would appear to merit real attention.

The investment in application research and development in the United Kingdom is clearly substantial, but it has been suggested that the Symposium today leads to the conclusion that there maybe some dissipation of the total investment. It is for examination, and discussion, as to how far the present research and development effort can be more effectively co-ordinated and channeled to ensure the overall improvement in application which must be the aim of all involved in the pesticide industry.

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Concluding Remarks on Symposium

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As far as I know, this is the first Symposium to be held in England on pesticide application which has included herbicidal aspects - a remarkable fact in view of the key role of application in the very extensive use of all classes of crop production chemicals during the past 20 years, and particularly in view of the growth in the use of herbicides.

It may be useful to reflect on the reasons for the relatively little progress that we all seem to agree has been made. Certainly, herbicides may, as has been suggested today, be partly to blame since very acceptable results were obtained with the early hormone weedkillers when applied through cheap low-volume equipment, the introduction of which had been preceded by negligible research. Their success has tended to give the impression that for crop spraying in general more sophisticated and expensive equipment is unnecessary.

Lack of progress can, perhaps, more seriously be attributed to what would appear to me to be certain characteristics of the three and hitherto rather isolated groups of people concerned with the development of techniques of pesticide applications.

The Machinery Manufacturer has had, I imagine, a restricted market, fierce competition and a relatively small demand for new equipment due to longevity of the old. Economic considerations alone have probably excluded basic research except in equipment design. It must also have been difficult for manufacturers to keep in touch with changing biological requirements. In any case how convincing has been the evidence that better methods of application involving more expense and possibly more equipment maintenance would be welcomed by users?

The Pesticide Manufacturer, with some notable exceptions, seems often to have been lacking in initiative in encouraging better methods of application. Mr. Parish admitted that the manufacturer will usually take the easy way out and make do with existing equipment for economic reasons unless special techniques are essential for the success of a particular product. Mr. Norman also accepted as inevitable that the vast numbers of applicators already in use would continue to be used for a long time to come regardless of their deficiencies. Perhaps looking back with hindsight, it would have been reasonable for pesticide manufacturers to have costed their products to allow more funds to be made available to subsidise R and D on application techniques.

Looking ahead to such novel techniques as ULV, it seems unlikely that the chemical manufacturer will wish to play a very positive role if a principal advantage is the reduction in the amount of pesticide used.

The Research Worker has often been content to work on isolated fragments of the problem - or indeed to ignore application factors altogether. The Engineer, who has undertaken much valuable testing of existing equipment, has shown up its faults and suggested improvements. He, together with the Physicist, who has made many contributions to our knowledge of droplet performance, has tended to wait for the biologist to provide precise specifications of application parameters for specific problems. The Biologist, on the other hand, has all too often either washed his hands of the whole business or waited hopefully for the engineer to provide the equipment to enable him to study the biological significance of different methods of application.

Inevitably, there is a resistance to change unless there is sufficient inducement. Advantages of new techniques must be proved and demonstrated to potential users if they are more expensive or more trouble. For this reason, R and D alone may not be sufficient to ensure the uptake of a worthwhile development. Demonstrations of economic and logistic advantages may be essential and I suggest that all attending this Symposium who are in a position to take action should consider seriously the allocation of part of their time to obtaining factual evidence of the benefits of the most efficient application attainable. Mr. Nordby's reference to a four-fold increase in efficiency of herbicides is tantalising.

Mr. Lloyd's paper raised the question of safety. With increasing dependence on chemicals and awareness of the possible hazards, much more work is going to have to be done on the safety of pesticide application methods. There will be new pressures to cut down drift both off the treated area and for the protection of the operator. More efficient application could also lead to lower costs, so urgently required today.

As the Duke of Edinburgh said at the recent European Conservation Year Conference at Strasbourg, the presentation of papers and discussions are not enough in themselves and are only effective if they lead to action. This Symposium has demonstrated that there is plenty of interest and talent available but that three important factors have, in the past, been scarce: liaison, collaboration and finance. The first two can be remedied through the organisation of further symposia of this type. The third is more difficult and it will probably be necessary to build up a case to demonstrate to those in authority the positive need and likely benefits of undertaking more intensive and comprehensive R and D in this subject. A very appropriate body to take on this task would seem to be the British Crop Protection Council's Application Committee whose Chairman, Mr. Evans is with us today. Perhaps he would be willing to take the initiative and build up on the efforts of Mr. Byass who has been responsible for this very successful meeting today.

SYMPOSIUM ON PESTICIDE APPLICATION

18th February 1970

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