SESSION 9

APPLICATION—IMPROVING EFFICIENCY AND SAFETY

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APPLICATION TECHNOLOGY: REVIEW AND PROSPECTS

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Summary. Following a brief statement of the important properties of sprays, the development of controlled drop application is reviewed and some field results given. Experimental work on electrically charged sprays and selective application is briefly reviewed. Aspects of sprayer design and use including provisions for boom stabilisation and improved management of spraying operations are considered, together with environmental implications. The outstanding problems and likely course of developments are outlined.

INTRODUCTION

In this review of developments in application technology over the last decade there is room for mention only of the most significant concerned with weed control in Europe.

Fundamental to much of the research work undertaken has been a steadily increasing awareness of the importance of the parameters which define a spray application. This is illustrated by comparing papers given at the British Weed Control Conferences in 1964 and 1966 with papers in the 1978 and 1980 Conferences. Papers giving full application details rose from 7 to 25%, and those giving none fell from 51 to 23%. This also shows there is still scope for further improvement in reporting all details of experimental procedures.

Research on the effects of the parameters defining a spray has made progress in recent years particularly through the availability of better methods for quantifying the characteristics of sprays. Also, more elegant and imformative work has stemmed from the development of means to separate some of the properties to study their effects individually.

Many workers have shown how herbicide response can be profoundly affected by drop size. This affects the ability of the spray to penetrate crop canopies and influences its retention on, or reflection from, plant surfaces. Experiments on the application of barban to wild oat plants showed that the physical properties of the spray could play a significant part in the performance of the material, drops of particular sizes being applied in a spinning disc cabinet (Lake and Taylor, 1971). Higher deposits on the leaves of wild oats and barley plants were obtained with 100 µm diameter drops than with drops of larger sizes. At high surface tension the difference was more pronounced, the 100 µm drops being little affected (Lake, 1977).

With conventional sprays biological response has been considerably altered by manipulation of volume and drop size spectrum using nozzles of different sizes and at different pressures (Taylor et al., 1974: Foden and Davies, 1974). In an examination of different nozzle arrangements in cereal spraying it was found that if the three factors - nozzle type, spacing and spray angle - were optimised the ground level deposits could be double those obtained with the worst combination (Andrews and Byass, 1977).

CONTROLLED DROP APPLICATION (CDA)

At some stage in the research work in which the spinning disc was used to make applications of drops of discrete sizes there was a subtle change from its use as a research tool to a recognition of its potential as a field spray application system. The discs first used at NIAE and WRO in laboratory work were flat and smooth. These produced drops around the periphery by direct formation at a very low throughput. For field plot work WRO developed units employing proprietary discs. These were stacked one above the other to produce an adequate output for an acceptable forward speed in experimental work and were shrouded to obtain a suitable transverse distribution (Taylor et al., 1976). When the "Herbi" disc was introduced it was adapted for use in the stack formation and Horstine Farmery Ltd. developed similar units. Much experimental work was carried out with these early devices on hand-held and tractor-mounted equipment.

Following the development of means for dependable formation of ligaments from spinning discs, by which means output could be increased by a factor of nearly 10 times (Frost, 1978), the "Battleship" spinning cup unit was introduced. Later, as the "Micromax", this was equipped with a two-speed drive, and then a three-speed drive, to produce drops of different sizes (Heijne, 1978).

Recent field experiments by ADAS have been carried out using applicators made at NIAE, using flat discs but with variable speed drives to obtain drops of different sizes. The side booms of these units were also equipped with spray lines to facilitate changes between conventional, reduced volume and controlled drop applications.

Within the last year the "Girojet" has been introduced from France - a novel form in which the spinning disc rotates in the vertical plane, all upward moving drops being collected and recycled, so that delivery is in the form of a downward flat fan of 140° spray angle (Morel, 1981). Similarity to previous systems is limited to the mechanism of drop formation and the behaviour of the drops must be significantly different from those produced by horizontal discs because of their high initial downwards velocity.

It is not possible within the space available to give a comprehensive review of the results of all the field trials of CDA but some may be mentioned. Major contributions have come from WRO, regional and EHF staff of ADAS and application specialists of agrochemical manufacturers. Early results from WRO indicated that with some materials CDA at rates of 20 l/ha and 40 l/ha gave results comparable to those obtained with conventional, 220 l/ha applications (Cussans and Taylor, 1976: Ayres, 1976). In early work ADAS obtained less favourable results though they were judged to be commercially acceptable (O'Keeffe et al, 1976: Evans and Kitchen, 1976: Bailey and Smartt, 1976). It should be observed, however, that in this early work the equipment used applied CDA in drops of 250 µm diameter, although earlier laboratory results had shown advantages for smaller drops.

Much of the early work was adequately reviewed in two papers presented in 1978 (Bailey et al., 1978: Linke, 1978). In the first of these, several results much less favourable to CDA were reported; weed control being in the 70-80% range in comparison with conventional applications. For the first time results were given for the use of reduced application rates with nozzles, showing performance equivalent to CDA, with much of the logistic advantage of CDA. At the same time WRO noted some inferior control by CDA, attributed to the failure of drops to penetrate the crop canopy where this was well developed (Ayres, 1978a). It was suggested that the greater number of spraying opportunities afforded by the freedom from drift of CDA and the better timeliness attainable through the reduced water requirement should compensate for any deficiency in weed control (Mayes and Blanchard, 1978). Poor performance due to uneven distribution from Battleship units was attributed to boom bounce (Lavers and Stovell, 1978). When poorer control of blackgrass was noted at WRO with CDA it was suggested that the ability to get on the land with a lighter CDA machine to remove early weed competition might offset a small loss in control compared with either a late application or none at all (Ayres, 1978b).

Reduced application rates with conventional nozzles obtained by use of higher forward speed was investigated at WRO. At 20 km/h a rate of 60 l/ha was obtained without detriment to standard of weed control and with the benefit of improved timeliness (Ayres, 1980). Recently, results have become available for the use of drop sizes other than 250 µm diameter. Performance of 150 µm diameter drops down to 10 l/ha was satisfactory at early growth stages but they were less effective in penetrating a canopy. Resistance to wind was acceptable if the drops were released close to the top of the crop, requiring a high standard of boom stability (Robinson, 1982). ADAS work with drops of 135, 175 and 265 µm diameter, showed the performance of the two larger sizes to be equal to conventional spraying, with no further advantage for the smallest size (Bailey et al, 1982a). Other ADAS results, to be presented at this Conference, indicate good prospects for CDA with drops in the range 155-175 µm diameter applied at 40 l/ha (Bailey et al, 1982b).

ELECTRICAL CHARGING OF SPRAYS

In the early 1970's the University of Sheffield started extending the expertise and knowledge gained in paint spraying with electrostatic charging to the possibility of pesticide application. The method used was to maintain a spinning disc atomizer at a high potential. This has been further developed at Rothamsted as the "APE 80" (Arnold and Pye, 1981). It was shown that the charge increased spray deposited on the lower parts of 12 cm high bean plants by about 2½ times, although when the plants were 90 cm high the penetration of charged spray to the lower parts was less than that of uncharged spray.

To obtain some indication of the prospects for electrical charging of agricultural sprays an experiment was carried out in the wind tunnel at NIAE. An electrical charge on 125 µm diameter drops released in a wind of 2 m/s was shown to increase the proportion intercepted by plants in trays in the first 2 metres downwind from 15% to 40%. Airborne amounts 2 metres downwind were reduced from about 70% to 7.5% (Byass et al, 1979)

The term 'electrodynamic energy' was used to describe a novel system of energy conversion for the dispersion and deposition of spray. In the "Electrodyn" unit electrical energy at high potential is applied directly to oil-based formulations to achieve atomisation and deposition (Coffee, 1979). A derivative of the original hand-held Electrodyn applicator which has an annular orifice is one in which the orifice is unrolled to produce a linear electrostatic spray source (Coffee, 1981: Wilson, 1982). In America extensive experiments have been carried out with charged spray from bi-fluid nozzles and increased deposition has been recorded on cabbage, broccoli, cotton and corn crops and on artificial targets within them (Law and Lane, 1981).

Spray from hydraulic nozzles has been electrostatically charged in Germany and deposits of drops of 150 µm diameter were more than doubled and those of 300 µm diameter drops were increased by 50% (Ganzelmeier and Moser, 1980). It was concluded that the system would be particularly appropriate for oil-based materials in ULV spraying. At WRO a pulsed microjet was adapted as a research tool. This prevents in-flight collision between drops after formation by inducing an electrical charge on them to cause mutual repulsion which also causes a very uniform spacing of deposit on the target (Stent et al, 1981).

Undoubtedly, the effects high voltages have on liquids is a complex subject. One effect on a bulk of liquid is to cause atomization, another is on the behaviour of drops carrying charge in their subsequent flight and impaction (Marchant, 1980). At NIAE a system has been developed for charging the spray from hydraulic nozzles without raising the potential of the bulk of liquid or of any structural parts. Spray deposits from a nozzle travelling at 2 m/s were increased between 1.3 and 2.8 times (Marchant and Green, 1982).

SELECTIVE APPLICATION - SELAP

An early selective application method was the roguing glove for wild oats. A height differential between the crop and the unwanted plants was first used in the control of bolting and wild beet in sugar beet crops. The offending foliage was sprayed with herbicide as it passed through a shroud from which the excess spray was recycled (Martens, 1974). Experiments with recirculating sprayers in USA indicated that a height differential of 45 cm was necessary. The need for such a system where the differential is much less led to the development of methods for wiping herbicide onto upstanding weed parts. The first was the rope-wick applicator (Dale, 1979). Other methods included continuous belts of porous material, carpet-pads, wax bars and rollers. In an American review it was concluded that the rope-wick was the most promising (Wills and McWhorter, 1981). Results to be presented at this Conference will show that at WRO, however, the performance of the rope-wick was found to be intermediate between the good performance of an experimental roller machine and that of a commercial roller device (Lutman et al, 1982).

Another approach has been to destroy plants projecting above the crop, or between the plant rows, by electrocution. The passage of electric current causes damage to the cell structure so that the plant will wither and die, possibly over several days. Alternatively, the plant may be given a very large shock sufficient to destroy it in a second or two. Experiments at Sheffield University have shown it to be an effective weed management system which is entirely pollution free (Diprose et al, 1978).

SPRAY BOOM STABILITY

In a 1970 survey measurements were taken of the movements of the boom and of the sprayer frame on a representative sample of machines operating in typical cereal spraying conditions. It was concluded that the main cause of the random boom movements was the transmission to the boom of the rapid rolling motion of the sprayer (Nation, 1982). In 1972 the dynamic behaviour of a sprayer boom was examined on different boom support systems, culminating in the development of the gimbal mounting (Nation and Holden, 1975). This reduced transmission to the boom of both rolling and yawing motions.

In Holland, laboratory measurements of spray deposit variations under booms excited with simple harmonic motion indicated that horizontal movements of the boom tips should be avoided entirely and the vertical movements should be no greater than 5 cm (Speelman and Jansen, 1974). Similar conclusions were reachec in Germany and at NIAE by calculation. Although distribution variations are much less with fan spray nozzles than with hollow cone spray nozzles if amplitude of vertical movement is small, variations with fan spray nozzles increase more rapidly as amplitude increases. For horizontal movement, variation in deposit increases linearly with amplitude., but fan sprays are worse than cone sprays. Because good fan spray nozzles give more accurate overlapping and transverse distribution they are preferred (Nation, 1980: Schmidt-Ott, 1975).

Besides contributing to more uniform spray distribution stable booms have other advantages. Higher speeds or longer booms, or both, may be used to increase work rate. Booms can be set closer to the target, improving penetration of spray through crop canopies and reducing the flight time of spray and thus the time when it is at risk of becoming drift. With low energy systems and particularly spinning discs rotating in the horizontal plane, a stable platform for the release of spray is essential. Most commercial developments were aimed at increasing work rate and reducing vertical movements and consequently the stabilizing methods were aimed at reducing roll. Thus they usually employed a single pivot pendulum, a centre pivot or a twin-link pendulum system.

For maximum improvement in spray distribution, stability in the horizontal plane is necessary. It can be obtained with single pivot-supported boom by relatively simple means and two or three makes of sprayer now have this provision.

Because of the popularity of twin-link suspensions a method by which these could be adapted to provide stability in the horizontal plane also was devised and patented by NIAE in 1978. (GB Patent 2,028,078). This has been termed the 'universal link suspension' because each of the suspension links terminates in universal joints. It is necessary to restrain the boom with respect to the sprayer frame at the boom centre by a method which does not impair the functioning of the suspension links (Nation, 1978a).

The gimbal mounting and the universal links suspension have similar performances, both are slightly more effective in the horizontal plane than the vertical and performance improves as speed increases. These suspensions are passive in their function: the gimbal suspension is in neutral equilibrium, the universal links and other pendulum suspensions are in stable equilibrium, depending on gravity to provide the restoring forces. It is also possible to arrange for restoring forces to be applied from a power source in response to signals of input disturbances. Such systems are active in function, and one form has been exploited on a large French sprayer.

SPRAYER OPERATION MANAGEMENT

The proper matching of successive swaths has been a problem for years. Despite very considerable investigations and development work and the availability of a range of devices and techniques it still remains a problem. Development of the foam-blob system with mirrors, electronic detectors, cameras and self-propelled flaggers have been reviewed (Lawrence, 1980). Tramlines provide an effective answer for those who are prepared to use them if they are laid out with care and accuracy. Navigational systems have been discussed but are not yet available. The most accurate and least troublesome swath matching is that achieved automatically by use of special designs of sprayers such as gantries and side-boom models, but these have a limited appeal.

The management of spraying has now assumed much greater importance in several respects. Timeliness is of the essence in so much spraying and so many factors have critical influences on this. One of these is the logistics of the operation; that is, providing back-up services to keep the sprayer in action for the maximum proportion of the opportunity. Application rate is of paramount importance, hence all the effort to reduce this, both with nozzles and novel systems. The complex interaction of all the variables can most readily be studied by use of a computer model of a typical days spraying. Parameters such as application rate, boom width, spraying speed, tank capacity, field size and so on, can be varied and their effects assessed rapidly (Nation, 1978b). Several manufacturers now cater for improved logistics and install high capacity self-fill pumps on sprayers and offer bowsers, spray mixers and front-mounted tanks.

Another aspect concerned with management to achieve timeliness has been the rapid acceptance of low ground pressure equipment to enable spraying to be carried out in autumn and winter. This has been an area of intense development activity, starting with work at WRO with an "Argocat" and a "Highland Garron" (Cussans and Ayres, 1978). Development has included adaption of cross-country vehicles, use of oversize tyres on tractors and construction of purpose-built agrochemical applicators (Elliott, 1980: Rutherford, 1980).

Timeliness has also been at the centre of the recent work on repeated applications with partial doses in overall spraying of sugar beet, when, through the higher work rate, each successive fresh flush of germinating weeds can be treated at their most susceptible stage (May, 1982).

Similarly, the increasingly popular practice of tank-mixing of different materials grew from pressure to complete more spraying with optimum timeliness within the limited opportunities available.

One of the most significant developments of recent years has been that of monitoring equipment and automatic volume regulators. Instrumentation has been made available to indicate to the operator his true forward speed and the flow rate to the boom. Integration of these two signals and other data has enabled him to be given an indication of instantaneous application rate, or error in this if a target value has been provided. By use of this error signal, automatic volume regulators can be arranged to control either pressure or flow rate to the boom to maintain the required applcation rate. Simpler methods use balanced by-pass systems which maintain delivery proportional to engine speed or land-wheel drives to relate it to forward speed (Givelet, 1981).

Monitoring equipment assists the operator in maintaining the required application rate as conditions change, either by adjustment of forward speed or pressure. Automatic systems relieve him of this duty entirely. However, there is a danger that, in relying on such equipment to maintain application rate constant over a wide range of speed, significant changes in drop size spectrum and distribution may occur because of the square law relationship between flow rate and pressure, with possibly unacceptable biological consequences. This disadvantage is avoided if a constant flow rate of water is delivered to the boom and the concentrate is metered in proportion to forward speed and injected into the flow. The system is not novel but is only now being evaluated for field spraying, in which the effects of varying concentrations may be important.

ENVIRONMENT AND SAFETY

The problem of spray drift remains as serious and topical as it has ever been. Indeed concern was expressed about it in the Report of the Royal Commission on the Environment in 1978 and there have since been many reports of incidents. There are three technical aspects - the measurement of drift, the mechanism of drift occurrence and methods for control of drift.

There have been many reports on experiments to measure spray drifting away from the application site and depositing elsewhere but there is often some difficulty in assessing the significance of the results because of uncertainties over the techniques employed. Now, however, there are indications that through better understanding of the factors involved a more common approach is being taken. At this Conference there is a paper showing how comparisons between two sources can be made by sampling them simultaneously using two different tracers (Lloyd and Bell, 1982). The paper also provides a concise description of the techniques used and the reasons for their choice.

An interesting development within the last decade has been the calculation or assessment of weather limitations on spraying. Subjective observations have been made as to when spraying would and would not have been possible and related to the weather at the time (Tottman & Phillipson, 1974).

Analyses have been made of weather records in the light of assumed criterion to establish the increase in spraying opportunities afforded if hydraulic nozzle spraying is replaced by CDA, with its increased drift resistance permitting spraying in higher wind speeds. On the basis of soil moisture deficits, estimates have also been made of the increased opportunities available through the use of low ground pressure equipment (Adams, 1978). Finally, considerable progress has recently been made in the development of models of the behaviour of spray drops as influenced by atmospheric conditions and the nature of the ground cover (Thompson, 1982). However, further work is needed to provide the link from the method of spray formation to the mathmatical model.

In the absence of a rigorous analysis of the occurrence of drift most of the means developed to control it have been empirical. CDA and possibly electrostatics are refined examples. More simple have been the use of low pressure nozzles and the addition of thickeners to the spray liquid, both with the object of coarsening the spray. Certainly, the use of lower pressure moves the whole drop size spectrum towards the larger end, but a small proportion of fine drops remains.

An interesting discovery by Dombrowski at Leeds University was that by the application of heat in the area below a hydraulic nozzle where the spray is formed the proportion of fine spray particles was very dramatically reduced. Despite commercial interest at the time, this has not yet been exploited.

Because the proportion of spray becoming drift increases very rapidly as boom height is increased a very substantial contribution to reduced drift can be made by improved boom stability, enabling booms to be set lower.

APPRAISAL AND PROSPECTS

There has been a general increase in recognition of the importance of the physical features of a spray and this can be expected to continue. Methods have been improved for measuring and quantifying these features by the application of significant developments in instrumentation and data handling technology. Progress has been made in separating the various factors and in examining the individual contribution of each to the overall result. The importance of the eventual site of retention and of plant architecture and surface characteristics have been demonstrated. As application rates continue to fall maximum possible retention at the most effective sites will be vital.

Most significant has been the development of CDA where the initial enthusiasm and atmosphere of optimism was replaced by some uncertainty as problems and circumstances were encounted where the performance of CDA gave cause for concern. Changes took place from the use of phases such as "comparable performance" to "commercially acceptable" and somtimes "inferior to" in making comparisons with conventional nozzle applications. Some of the poorer results were attributed to questionable experimental methods and inadequate control of the applications but this was countered by the view that a high standard of application could not be depended upon in commercial use. Problems occurred in two main areas - the performance of contact-acting materials and the failure of CDA sprays to penetrate cereal canopies adequately. Variable distribution was also criticised in some cases.

Recently, there has been a new enthusiasm for the method. The performance of contact-acting materials has been improved by use of smaller drop sizes for better cover at low rates. Use at earlier growth stages, particularly in the autumn, has avoided some of the penetration problem. Use of stabilised booms has reduced distribution variations - indeed, a stable platform is increasingly recognised as essential for low volume and low energy application systems. It has also become apparent that care must be taken in the feed of liquid to spinning discs to ensure even spread over the disc surface if distribution variation is to be avoided.

The use of air currents to assist the transport of uniform-sized drops towards the target featured in early laboratory work and later in field plot experiments with a CDA-type applicator at NIAE. It was apparent that a delicate balance between the amount of air and its velocity is required to render a useful degree of assistance to spray transport and cause movement of the crop canopy without spray-laden air being reflected from the ground and out of the crop. It is expected that this principle will be investigated again in the immediate future and probably exploited commercially on CDA sprayers. Alternatively, it would appear that there may be some potential for the aerofoil principle, particularly on high-speed sprayers (Lake et al., 1982).

It should not be assumed that the hydraulic pressure nozzle is near the end of its working life in agricultural spraying. The results which have been obtained in its use at low application rates, coupled with its cheapness and simplicity, will ensure its continued use. It is particularly appropriate in the new vogue for higher spraying speeds where, in well-established types and sizes, it can apply the reduced rates. Much of the success of the hydraulic nozzle may lie in the spread of drop size it provides, spanning what may be the various optimum sizes for a range of differing requirements occurring within one practical situation. Controlled drop applicators may be designed to provide different drop sizes, as required, by adjustment of disc speed but may also have provision for bi-modal or broad spread size distributions to imitate this feature of hydraulic pressure nozzles without the disadvantages of waste of material in large drops and drift hazard of the small ones. Also, by the application of new technology and at some increase in cost the design of nozzles may be so altered in the future to give them more acceptable characteristics and performance.

The way ahead for electrostatics in herbicide application is not yet clear. There are insufficient practical results available to enable judgements to be made. The different methods used to charge the spray from a hydraulic nozzle in Germany and at NIAE, the use of the bi-fluid nozzle in USA, the charging of spinning disc sprays and the novel system of the "Electrodyn" indicate that the subject is being tackled across a wide front. Which of these systems will eventually prove to be most appropriate in the subject area of this Conference cannot yet be predicted. A paper at this conference presents the first field results with charged herbicide sprays (Parham, 1982).

The downwards propulsive force-effect of the space charge of the spray cloud and of the lines of force due to the charge source may have similar effects to the air assistance of CDA sprays in aiding canopy penetration but the attaction of the spray particles towards foliage from all directions may be a bonus or it may be counter-productive. Without air movement it is unlikely that there will be foliage movement and it may be beneficial, therefore, for these charged sprays to be assisted with air currents.

Research at NIAE is aimed at obtaining a better understanding of the behaviour of charged spray clouds and particles and of the factors affecting their movement from source to target. Development work and laboratory and field assessments will continue there and at several other centres both in the Agricultural Research Service and in industry.

Selap has given mixed results from a variety of developmental approaches. More fundamental studies of where, and how much, herbicide is retained on the target weeds has given some useful pointers and more of this work is required. Although the early work in USA was with recirculating sprayers, these have not been investigated in detail in Europe, where the preference has been for the various types of wiper. It has been interesting to see that with the roller type of applicator the direction of rotation of the roller seems to have an important effect. The requirement remains for a transfer system or mechanism which will leave herbicide on more than one side of the target plant from only one passage through the crop. To make full use of the height-differential it may be necessary to incorporate stabilising means similar to those for spray booms or to have height-gauging means. The exploitation of electrical discharge weeding and of detection of target plants or areas by electronic or photoelectric means for spot treatment is likely to be limited to use in crops which do not grow to a uniform height and preclude the use of height differential, or to other special circumstances.

Of the 20-odd companies now offering sprayers to UK farmers, there are only one or two not providing some form of boom suspension for improved stability, either standard or as an option. Whilst suspension to reduce height variations of boom tips has most generally been adopted, suspension to reduce yawing movements has only recently begun to make progress commercially. With the continuing wide use of fan spray nozzles and the trend towards low application rates stability in both planes is required if standards of distribution are to be maintained or improved.

If the trends continue towards lower application rates by coventional methods, to wider use of very low rates by specific systems and higher standards of logistic servicing become more widespread it can be expected that high-speed spraying by light, versatile, purpose-built sprayers will become more common. However, there will not be any early or dramatic change in the composition of the 6,000-odd new sprayer sales in the UK each year, although many of the existing types of sprayer can be expected to become more sophisticated, particularly in control gear.

The extent to which the standard of boom stability attainable with present technology can achieve a standard of spray distribution beyond which further improvement would not show greater returns or benefit has not been established. The agronomic and economic significance of spray distribution variation is not quantifiable except through very considerable effort. Thus, it is not possible to be categorical on an acceptable threshold standard of stability or on the justification for more complicated systems such as active stabilising systems or outrigger support or gauging wheels.

The use of low ground pressure equipment has been the most rapid of recent developments. As suitable oversize tyres have become more readily available there has been a return, to some extent, to equipping the general-purpose tractor with mounted sprayer for low-ground-pressure operation in preference to the purchase of adapted cross-country vehicles or purpose-built, multi-use sprayers, with interchangeable wheel equipment. However, because these larger tyres are generally more heavily treaded it may be that, although they provide the required trafficability in poor conditions, they may be somewhat more damaging than the less heavily-treaded smaller tyres. This is an area in which some of the effects deserve quantification.

Developments in instrumentation and automatic control will continue and the purpose-built sprayer possibly offers the best scope for these to be fully exploited. If developments in chemical packaging and handling are forced, by considerations of operator safety, in the direction of those in California, with the introduction of closed systems for transfer of scheduled chemicals from package to sprayer one can envisage a system with which the operator can select his application rate of water, the dose rate of chemical and the median drop size of the spray. The sophisticated sprayer should also be equipped for automatic swath matching, either based on the existing practice of tramlines or by pick-up from the previous bout sprayed. There is scope, too, for monitoring various functions, for example, tank contents, individual nozzle or atomiser behaviour and boom stability.

Within the space of this review it has not been possible to cover every aspect of application technology, but it is hoped that those areas in which there have been significant developments have been included. It is also hoped that some of the areas in which future work will, or should take place, have been indicated. The challenges presented to researchers, developers, advisors and entrepreneurs are exciting - further developments in application systems, more controlled CDA for better cover and penetration, electrostatic charging when beneficial at the touch of a switch, monitoring and automatic control of more functions, reduced dependance on weather conditions, more care of the operator in terms of safety and less arduous duty and finally, increased work rates and reduced costs.

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THE RESULTS OF AN INVESTIGATION TO DETERMINE THE OPTIMUM DROP SIZE AND VOLUME OF APPLICATION FOR WEED CONTROL WITH SPINNING DISC APPLICATORS

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Summary Six experiments are described in which various combinations of drop size and volume of application have been compared with respect to control of broad-leaved weeds and *Alopecurus myosuroides*. Applications at 40 l/ha were superior to those at 20 l/ha. Variations in drop size resulted in broad-leaved weed control of 71.1, 76.3 and 70.0 percent for CDA 125, CDA 157 and CDA 250 respectively. Control of *A. myosuroides* with isoproturon was not affected by drop size. CDA, drop size, volume of application, spinning disc, reduced rates.

INTRODUCTION

The use of Controlled Drop Application (CDA), as a means of applying spray chemicals to cereal crops within the U.K., has recently shown a marked increase. The present interest in the technique, as shown by farmers as well as researchers, follows a very hesitant attitude adopted initially. The earlier doubts surrounding the technique arose from the somewhat disappointing results obtained in various quarters. As an example, the herbicide experiments executed by the Agricultural Development and Advisory Service indicated that CDA generally resulted in only 80% of the weed control produced by a commercial technique viz. hydraulic nozzles (Bailey and Smartt, 1976; Bailey et al, 1978 a; Bailey et at 1978 b).

It is important to note, however, that in all of these earlier experiments, the drop size used for the CDA technique was approximately 250µm. Recently, there have been indications that a much more effective result can be attained if a drop size of 155-175µm were used, (Phillips et al, 1980; Bailey et al, 1982) although this does not always appear to be the case (Ayres 1982).

The experiments described here were designed to further study the effect of drop size upon the efficiency of the CDA technique, and to observe the relationship between drop size and volume of application. Furthermore, as previous studies of this nature have dealt mainly with the application of broad-leaved weed and spring-applied wild oat herbicide two experiments were designed to observe the effect of drop size and volume of application upon the control of blackgrass using isoproturon.

Finally, there have been unpublished reports concerning the high effectiveness of certain chemicals when applied at low rates with a CDA technique. In order to test this, one blackgrass experiment contained a half-rate application at different drop sizes.

METHOD AND MATERIALS

The field trials were established on six sites, each site consisting of a randomised block design with three replicates.

1. The blackgrass experiments

The sprayer used was one designed and built by the National Institute of Agricultural Engineering. It is tractor mounted, with a 4 metre boom and has the capability of CDA with a range of drop sizes, or conventional hydraulic spraying. It is more fully described by Phillips et al (1980). The herbicide used was isoproturon.

2. The broad-leaved weed experiments

The farmers own CDA sprayer was used on the Bristol site; the rotary atomisers were of the "Micromax" design. Elsewhere, the sprayer described above was used.

Further details of each experiment are provided in the appropriate section.

RESULTS

1. The Thurleigh blackgrass experiment

In this experiment, commercial hydraulic spraying was compared with CDA at 20, 40, 60 and 80 l/ha using drop sizes of 125, 157 and 250μm diameter. Treatments were applied on 27 March. Owing to this late time of application, marked differences are expected between effective and non-effective treatments. A half-rate treatment was also included at each drop size, using CDA at 20 l/ha application rate.

To assess the effect of the treatments, 5 quadrats, each of $1/10m^2$, were placed within each plot in late June, and every blackgrass head within that area was counted. The areas were then sub-sampled for head length measurement in order that a measurement of total blackgrass head length per m^2 could be calculated. The results are expressed in Table 1 as a percentage control.

Table 1

Percentage blackgrass control from CDA and hydraulic nozzle treatments - Thurleigh

Drop Diameter	Full rate chemical Volume of application l/ha					½ rate chemical l/ha
	20	40	60	80	Mean	20
125 μm	60.2	78.5	85.6	66.9	72.8	20.7
157 μm	66.9	88.2	84.3	62.8	75.6	45.0
250 μm	62.7	79.7	85.2	71.8	74.9	55.2
Mean	63.3	82.1	85.0	67.2		40.3

Conventional application gave 81.2% control

SED when comparing drop diameters is ± 3.4

SED when comparing volumes of application is ± 4.0

SED when comparing commercial application with other treatments is ± 6.8

From these results, it can be seen that ½ rate applications were inferior to full rate applications. Further, it is evident that drop size has had no effect, whilst volume of application has had a marked effect. In this experiment, 40 and 60 l/ha applications were superior to 20 and 80 l/ha applications. There was no interaction between volume of application and drop size. Finally, the 40 and 60 l/ha applications were as equally effective as conventional spraying.

2. The Hilton blackgrass experiment

In this experiment, commercial hydraulic spraying was compared with CDA at 10, 15, 20, 40, 60 and 80 l/ha using drop sizes of 125, 157 and 250 μm diameter. Treatments were applied on 5 April. A subsequent application of HBN esters and mecoprop was applied but broad-leaved weed populations were too variable to enable any conclusions to be drawn. The treatments were assessed as described previously. The results are expressed in Table 2 as a percentage control.

From these results, it can be seen that, once again, drop size has had no effect, whilst volume of application has had a marked effect upon blackgrass control, the 40, 60 and 80 l/ha applications being superior to 10, 15 or 20 l/ha applications. There was no interaction between volume of application and drop size.

Table 2

Percentage blackgrass control from CDA and hydraulic nozzle treatments - Hilton

Drop diameter	Volume of application l/ha						
	10	15	20	40	60	80	mean (SED = ± 7.8)
125 µm	52.4	52.9	38.7	68.6	62.1	71.6	57.7
157 µm	33.8	24.8	60.4	59.8	79.0	56.4	52.4
250 µm	49.0	67.5	27.2	71.3	66.6	69.8	58.6
			(SED = ± 11.0)				
mean	45.1	48.4	42.1	66.6	69.3	65.9	

Conventional application gave 88.1% control

SED for comparing conventional with CDA treatments is ± 18.1

3. The Runhall broad-leaved weed experiment.

In this experiment, conventional hydraulic spraying was compared with CDA at 20, 40, 60 and 80 l/ha using the same drop sizes as above. The herbicide used was a tank mix of isoproturon/mecoprop, applied on 15-18 February. To assess the effect of the treatments, quadrats, each of 0.1m^2, were placed within each plot on 20 May, and every plant within that area was counted. The results are expressed in Table 3. The predominant weed species were *Galium aparine*, *Myosotis arvensis* and *Veronica* spp. However, presumably due to cold temperatures, all treatments failed to control *G. aparine* and it has therefore been excluded from the assessments.

Table 3

Percentage broad-leaved weed control from CDA and hydraulic nozzle treatments

Drop diameter	Volume of application l/ha				
	20	40	60	80	mean (SED = ± 2.32)
125 µm	87.4	74.9	63.3	83.9	77.4
157 µm	87.9	85.4	88.4	91.5	88.3
250 µm	87.4	85.9	83.4	88.4	86.3
		(SED = ± 2.68)			
mean	87.6	82.1	78.4	87.9	

Conventional application gave 93.0% control

SED for comparing conventional with CDA treatments is ± 4.53

From the results, it can be seen that drop size has had an effect, volume of application has had effect, and furthermore, there is a significant interaction between drop size and volume of application (SED = ± 11.81). It is evident from the data that all of these effects are due to inferior control shown by 125 µm drops at 40 and 60 l/ha.

4. The other broad-leaved weed control experiments

In these experiments, CDA was used at 10, 20, 40 and 80 l/ha, with 125, 157 and 250 µm drop diameters. The herbicide used was a bromoxynil, ioxynil and mecoprop mixture. The results are expressed in Table 4 as percentage broad-leaved weed control.

Table 4

Percentage broad-leaved weed control from CDA and hydraulic nozzle treatments

Volume of application

	High Mowthorpe					Bridgets					Bristol				
Drop diameter	10	20	40	80	mean	10	20	40	80	mean	10	20	40	80	mean
125 µm	27	43	69	54	48	62	86	76	92	79	68	77	87	(87)*	80
157 µm	36	55	74	70	59	66	79	85	89	80	78	73	80	82	78
250 µm	22	29	68	58	43	73	61	85	73	73	72	68	79	87	77
mean	28	42	71	59		67	75	82	85		72	72	82	85	
Conventional application					85					93					64

* value estimated by missing plot analysis

Mean over 3 sites

Drop diameter	10	20	40	80	mean (SED = ± 3.58)
125 µm	52.3	68.7	77.3	77.7	69.0
157 µm	60.0	69.0	79.7	80.3	72.3
250 µm	55.7	52.7	77.3	72.7	64.6
		(SED = ± 4.13)			
mean	56.0	63.4	78.1	76.9	
Conventional application					80.7

SED for comparing conventional with CDA treatments is ± 8.83

From the results, it is apparent that drop size has had no significant effect on efficiency of weed control, although there is a tendency for the data to follow the trend seen in previous years. Furthermore, applications at 40 l/ha and 80 l/ha were superior to applications at 10 l/ha and 20 l/ha. There was no interaction between drop size and volume of application.

DISCUSSION

In their capacity as Agricultural Advisors with ADAS, the present authors are aware of an increasing number of enquiries from farmers regarding CDA. Furthermore, many of these enquiries concern the possibility of reducing chemical dose rates, especially with regard to the more expensive herbicides. Although there is no published evidence to support such a practice, we have observed farmers attempting to control A. myosuroides in cereals using CDA with only half of the commercially recommended rate of chemical. As a result of these observations, half rate isoproturon was included in the experiment at Thurleigh, and resulted in very poor control of A. myosuroides. Although it is ackowledged that the timing of application was late, it is considered that the level of control (mean of half rate application was 40.3%) compared with conventional application (81.2%) demonstrates the reduced efficiency of this practice.

It is therefore concluded that, in view of this evidence, there is no firm basis on which to advice a farmer to use reduced rates of this herbicide because he has adopted a CDA technique, but, regardless of the technique used, we would recommend the full application of the chemical manufacturers recommended rate. This is especially true of those chemicals applied to control annual grass weeds.

This naturally leads to a discussion of the suitability of the technique for blackgrass control, even though full rates are used.

Previous experiments (Bailey et al, 1978;) have provided confusing results in that, although no statistically significant difference has been found between conventional application and CDA 250, the figures indicate that CDA is slightly inferior to conventional volume spraying in terms of weed control, particularly for post-emergence applications. As is always the case with such results, individual interpretations vary depending on the rigid way with which individuals adhere to the commonly employed statistical level of probability i.e. 95%. Until enough data is available to conclusively prove that a CDA technique is as efficient as conventional spraying, with regard to blackgrass control, the present authors have advised caution on the basis that if the 6% reduction in blackgrass control reported earlier is a real decrease, commercial adoption of the technique would be a step in the wrong direction.

As this problem is still unresolved with respect to CDA 250, the experiments described here were carried out in order to observe the situation with regard to smaller drop sizes. Firstly, it would appear that drop size has had no effect whatsoever. Thus, with regard to late post-emergence applications, a change in drop size is unlikely to achieve enhanced control of blackgrass. Secondly, the results show a marked effect due to volume of application. It would appear that volumes of 20 l/ha or less are unsuitable for blackgrass control at this time.

Applications at 80 l/ha have given conflicting results, i.e. good in one trial and poor in another. The cause of this is difficult to determine, but it should be pointed out that in the trial in which a poor result was obtained, variation in control across the spray boom width was observed, resulting in a striped appearance of the crop. In order to apply this treatment, forward speed was reduced to 2 m.p.h.; this speed and the still air conditions prevailing at the time, may have combined to affect distribution of chemical within the crop.

With regard to the application rates of 40 and 60 l/ha, difficulty arises as with previous work i.e. there is no significant difference between CDA and conventional application, but the mean percentage blackgrass control is 74.4, 77.2 and 84.7% for 40 l/ha, 60 l/ha and conventional application respectively. Although not statistically significant, the disparity between the means indicates that further work is necessary before wide-scale adoption of CDA for late control of blackgrass can be advised.

The situation with regard to CDA and broad-leaved weed control has, on the other hand, always been very different. In this case, the disparity between CDA 250 and conventional application is often so great, sometimes up to 20%, that the application methods can be shown statistically to be significantly different. However, unless the weed population is very high, differences in yield are unlikely to be observed and therefore a CDA 250 technique is probably suitable in some situations.

Nevertheless, if CDA were to be adopted on a wide scale commercially, it would need to provide good results in the majority of situations. Thus the present authors embarked on an experimental programme designed to determine whether changes in drop size or volume of application would improve results. Previous experiments, (Philips et al, Bailey et al 1982) have clearly shown an improved weed control from CDA 175 compared with CDA 265, but no further improvement by reducing drop size to 135 µm. In fact, CDA 125-135 has been very inconsistant in its performance, on some occassions giving perfect weed control and at other times performing very poorly, apparently without obvious explanation. In order to study this in more detail, the broad-leaved weed experiments described here were carried out.

Once again, CDA 125 has been very inconsistant in performance, such that in the Runhall experiment it has been shown to be significantly inferior to CDA 157, CDA 250 and conventional application. In view of these results, and previous years, it is concluded that CDA 125-135 is probably not the optimum drop size for broad-leaved weed control; although it performs very well on occasion, it rarely gives a superior result to CDA 155-175.

There is not a clear advantage, in these experiments, shown by CDA 157 compared with CDA 250, although the mean figures do follow the same trend shown in previous years (CDA 157: 76.3; CDA 250: 70.0;) in terms of percentage weed control. Taking three years experiments into consideration, present authors advise that future research and development should place more emphasis on CDA 150-175 than on CDA 250.

The present experiments also show a very clear advantage of using 40 l/ha applications in preference to 20 l/ha or less. As this has been shown in many experiments in the past, we can confidently conclude that 40 l/ha applications are far more reliable than 20 l/ha applications, and any commercial recommendations for CDA should take this into account.

To conclude, therefore, the most promising parameters for successful weed control with CDA appear to be 40 l/ha applications and 155-175 µm diameter drops.

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THE CHEMICAL ESTIMATION AND BIOLOGICAL ACTIVITY OF GLYPHOSATE DEPOSITED ON FOUR PLANT SPECIES BY ONE ROPE WICK AND TWO ROLLER APPLICATORS

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Summary The deposition of glyphosate (180 g/l a.e.) on thistles (*Cirsium arvense*), potatoes (*Solanum tuberosum*), docks (*Rumex obtusifolius*) and annual beet (*Beta vulgaris*) from three selective herbicide applicators was measured and was related to subsequent activity on the target plants. The machines deposited between 16.0 and 0.04 mg glyphosate/g dry wt. on the wiped plants. The prototype WRO roller, applying glyphosate thickened with alginate, deposited the most herbicide and the commercial roller, using glyphosate thickened slightly with a non-ionic polyacrylamide gel deposited the least. The rope wick using glyphosate diluted in water only was intermediate in performance. The docks and potatoes, retained more herbicide than the annual beet and thistles. Herbicide activity on the potatoes and thistles was acceptable when the deposition exceeded 1-2 mg/g (≡ 10-20 mg/plant). All treatments controlled the docks but activity on the weed beet, which retained least glyphosate, was poor. The results are discussed in relation to the variability in the field performance of selective, herbicide applicators. Thistles, potatoes, docks, weed beet.

INTRODUCTION

The possibility of using height differential between crops and weeds to achieve selectivity has been under investigation for a number of years. It is an attractive technique for the control of tall weeds in shorter crops. Non-mechanical methods (e.g. roguing glove; Holroyd, 1972) have been available for several years. More recently a range of machines has been developed, including recirculating sprayers (McWhorter, 1970), rotating rollers (Wyse & Habstritt, 1977) and, most recently, rope-wick applicators (Dale, 1979). Although these applicators are widely used in the USA, more than 4 million hectares were treated in 1979 (Wills & McWorter, 1981), little background research has been done into how they work. Excellent control of the target weeds can be achieved but there are many reports of variable or unsatisfactory performance (Dutt, 1981; Fawcett, 1980; Furrer *et al.*, 1980; Poisson, 1981). Frequently it is not clear why the treatments failed.

Research at the Weed Research Organization has indicated that it may be possible to achieve control of tall weeds such as wild-oats in cereals, docks in grassland and volunteer potatoes in sugar beet, with glyphosate (Holroyd, 1972; Oswald, 1978; Lutman, 1979). Initially this work was done with hand applications but subsequently a prototype rotating roller applicator was used.

The experiments described in this paper were carried out to provide detailed basic information on the potential of three applicators, the prototype WRO roller, a commercial roller+ and a rope wick applicator*, to apply glyphosate to tall weeds and subsequently to achieve control.

+ Manufactured by Adville Engineering, 1981 Ltd.
* Manufactured by Hectaspan Ltd.

MATERIALS AND METHODS

Four weed species of differing growth habits, Cirsium arvense, Solanum tuberosum, Rumex obtusifolius, Beta vulgaris) were established in pots during 1981. Details of the size of the plants and heights of the applicators are given in Table 1. Docks and thistles were treated on 18 June and potatoes, weed beet (annual beet) and thistles on 30/31 July. Artificial targets (plastic labels, 9 x 6 cm on a 25 cm stem) were also set up on 30/31 July. Plants of each species were set out in a line (50 cm apart) and the applicators were driven or pushed over the plants so that each was treated with the same part of each applicator. The rope wick and commercial roller were mounted on a tractor whilst the WRO roller was pushed by hand. For most species every other plant in the line was used for glyphosate determination whilst the remainder were used for assessments of biological activity.

Application techniques

Hectaspan rope wick This applicator was a pipe-wick similar to that described by Dale (1979). It consists of short overlapping lengths of nylon rope inserted at both ends into a 1 m length of plastic pipe which acted as the herbicide reservoir. The herbicide moved by capillary action down the ropes which were aligned so that the target weeds brushed against the ropes as the applicator moved forwards. Two 1 m units were used. The reservoir of each unit was filled with 1 litre of a solution containing glyphosate at a concentration of 180 g/l (a.e.)

Adville roller This applicator consists of a smooth plastic roller (25 cm diameter), electrically driven, revolving at 21 revs/min so that its underside moved in a forwards direction. It was fed with herbicide from a smaller 'fabric' covered roller which acted as the herbicide reservoir. The feed roller was partially filled with 4 litres of a mixture containing 180 g/l (a.e.) glyphosate and either 80 or 60 ml of a non-ionic polyacrylamide gel (Admongel). This mixture produced a thickened liquid which formed a layer on the plastic application roller that was wiped onto the target weeds as the roller rotated.

WRO Roller The WRO prototype roller applicator was basically similar to the Adville machine. A plastic roller (25 cm diameter), either with or without a 1 cm sponge covering, was mounted on a wheeled frame and was rotated manually. A herbicide 'gel' was used. One litre of a solution containing 180 g glyphosate (a.e.) was thickened with 30 g sodium alginate and 15 g calcium citrate (Oswald, 1978). This mixture was applied to the roller from a perforated plastic gutter mounted above it. The roller was rotated at approximately 21 revs/min so that, unlike the Adville machine, the bottom of the roller moved backwards.

All three machines, were operated at 1.5 and 6 km/h. Details are given in Table 1. All the glyphosate mixtures contained 1 g/l Tinopal CBS, a fluorescent dye, which was used to identify the position of the glyphosate on the weeds.

Chemical analysis

The glyphosate deposited on the plants was estimated directly by polarography. Within 30 mins of application the plants were shaken with 100 ml de-ionised water in a polyethylene bag (potatoes, docks, weed beet) or a stoppered glass cylinder (thistles). An aliquot of solution, now containing the glyphosate, was nitrosoated and was then estimated using a PARC 174a polarographic analyser, with a dropping mercury electrode (Byast, 1977). Tests were done prior to the two experiments to ensure that the varying mixtures with glyphosate did not affect the analysis and to check that all the glyphosate applied to the plants could be recovered and measured reliably.

After washing, the plant samples were dried and weighed so that the glyphosate deposition could be expressed in mg glyphosate/g dry wt.

Prior to the analysis the plants were placed under a UV light and notes were taken of the position of the deposits.

Biological assessments (plants not used for glyphosate determination)

The thistles treated in June were visually assessed 11 and 18 days after treatment, and the % green material recorded. On 13 July all the above ground parts of the plants were harvested and weighed. The docks were scored on a 0-9 scale for the amount of green foliage (0 = none, 9 = as controls) every 10 days after treatment. After 60 days the green material present on the plants was harvested, dried and weighed. The potato plants were scored on a 1-5 scale (1 = dead, 5 = healthy) on 12 Aug. and 4 Sept. On 8 October the number and weights of tubers/plant were recorded. These tubers were kept in a cool store during the winter and the numbers of healthy and deformed sprouts produced were recorded between March and May 1982. A visual assessment of the effects of the glyphosate on the weed beet was carried out in August.

RESULTS

Deposition of glyphosate

WRO Roller This machine deposited the most glyphosate on the target plants (Table 1). Many plants received more than 10 mg/g of glyphosate and only the July treated thistles reduced less than 1 mg/g. There are indications that the deposition on the docks at 6 km/h when the roller was sponge covered was lower than that from the other dock treatments. Overall, forward speed had no significant effect. The weed beet and thistles treated in July retained the least herbicide and the artificial targets the most.

Hectaspan rope wick The glyphosate deposition from this machine was lower than that from the WRO roller, achieving a maximum of 3.34 mg/g and a minimum of 0.37 mg/g (Table 1). There was no consistent effect of forward speed on deposition. Tilting the ropes so that they faced downwards at 45° increased the deposition, particularly with the thistles (July) and the artifical targets. As with the WRO roller, the weed beet and July treated thistles retained the least glyphosate and the docks the most.

There were indications from all the plants and the artificial targets that those at the front of the treatment line received more glyphosate than those nearer to the end (Fig. 1).

Adville roller. This roller applied the least amount of glyphosate to the plants, with a maximum of 1.3 mg/g and a minimum of 0.4 mg/g (Table 1). The higher forward speed resulted in significantly lower amounts of glyphosate being deposited on most target plants. The amount of Admongel in the herbicide mixture, with the exception of the 80 ml treatments applied in July did not have a great effect on the level of deposition. As with the other two applicators the thistles and weed beet retained the least herbicide.

Position of deposits

The WRO roller deposited most of the glyphosate on the edges of the upper surfaces of the leaves and on the stems, of the upper parts of the plants. Because of the relatively large amounts of gel deposited, some dripped onto the lower leaves and soil. In contrast, the Adville roller put most herbicide on the edges of the undersides of the leaves. The rope wick, unlike the rollers, placed most glyphosate on the stems and petioles, especially on those areas of the plants first touched by the ropes.

Table 1

The deposition of glyphosate (mg/g) from the three applicators on the target weeds. (Figures in brackets = log 10 (100x))

Applicator	Speed (km/h)	Docks (June)	Thistles (June)	Potatoes (July)	Weed Beet (July)	Thistles (July)	Artificial Targets (July) (mg/target)
Plant height (cm)		20-25	52-73	35-50	50-100	50-80	24
Plant dry wt (g)		4.18	9.53	12.1	13.4	11.1	
Height of applicator above the ground (cm)		10	20	22	34	16	18
WRO Roller (Sponge covered)	1.5	12.7 (3.00)	6.45 (2.77)				
	6	2.14 (2.27)	8.08 (2.81)				
WRO Roller (Smooth plastic)	1.5	14.0 (2.98)		10.5 (2.97)	2.85 (2.43)	0.91 (1.84)	64.2 (3.70)
	6	16.0 (3.19)	6.62 (2.81)				
Hectaspan rope-wick (horizontal)	1.5	3.34 (2.44)	1.40 (2.05)	0.81 (1.84)	0.46 (1.55)	0.37 (1.43)	0.76 (1.30)
	6	2.44 (2.36)	1.06 (1.76)	1.18 (2.00)	0.40 (1.50)	0.58 (1.61)	2.53 (2.34)
(wick at 45°)	1.5			1.13 (2.00)	0.49 (1.62)	0.90 (1.94)	2.62 (2.30)
Adville roller (80 Admongel)	1.5	1.33 (2.09)	0.13 (1.09)	0.12 (0.84)	0.07 (0.80)	0.06 (0.69)	1.44 (2.14)
	6	0.34 (1.66)	0.04 (0.53)				
(60 ml Admongel)	1.5			0.82 (1.89)	0.15 (1.09)	0.09 (0.86)	5.67 (2,72)
	6			0.40 (1.61)	0.12 (1.06)	0.04 (0.49)	1.47 (2.06)
ESE of mean		n = 10 (0.096)	n = 8 (0.106)	n = 8 (0.079)	n = 8 (0.083)	n = 8 (0.116)	n = 16 (0.083

Table 2

The effects of the selective application treatments on potatoes docks and thistles

		Potatoes		Docks		Thistles	
Applicator	Speed (km/h)	Damage Score (4.9.81)	No. of healthy tuber/ Plant (8.10.81)	Damage Score (20 days)	Dry Wts of green material /plant/g (60 days)	% Necrosis (11 days)	Fresh wt shoots (g) (25 days)
WRO roller (Sponge covered)	1.5			2.8	0.48	46	23.4
	6			3.1	0.84	22	28.7
WRO roller	1.5	1.0	0 (0)*	1.2	0.07	-	-
(Smooth plastic)	6			2.3	0.61	46	22.7
Hectaspan rope-Wick (horizontal)	1.5	3.4	2.6 (1.62)	3.2	0.69	31	28.9
	6	2.8	1.0 (0.64)	3.8	0.92	25	33.6
(wicks at 45°)	1.5	2.6	0.2 (0.29)				
Adville roller (80 ml Admongel)	1.5	4.4	7.1 (2.83)	3.7	1.00	8	63.7
	6			3.2	0.99	8	54.7
(60 ml Admongel)	1.5	3.9	2.1 (1.30)				
	6	3.8	3.6 (1.94)				
Control		5.0	10.1 (2.97)	9	7.21	0	64.0
Standard error of mean			(0.31)		0.20 (excluding control)		3.87

* Log 10 (100 x + 1)

Biological assessments

Potatoes Only the glyphosate deposited on the potatoes by the WRO roller killed the plants. (Table 2). Those treated with the Hectaspan, particularly when the ropes were angled down at 45°, showed severe damage to the apex and upper leaves. Only small amounts of apical necrosis were noted on those treated with the Adville roller. Although the partially effective treatments failed to prevent tuber production and in some cases stimulated the formation of small tubers, few of them produced normal healthy sprouts (Table 2). The Adville roller had less effect than the rope wick. The latter machine at the slower speed with the ropes horizontal was less effective than the other two treatments. Higher forward speed did not improve the performance of the Adville roller, but the 80 ml Admongel treatment was inferior to the 60 ml ones.

Docks All treatments caused severe damage to the docks, symptoms developing within 10 days of treatment. Only a third or less of each plant remained green after 20 days (Table 2). The plants treated with the WRO roller were slightly more affected than those treated with the other two applicators. The dry weights of green material recorded after 60 days show few differences between treatments, but all reduced the amount of green material by over 85% compared to the controls.

Thistles (June application) By the 29 June (11 days after treatment) many of the thistles had become necrotic, particularly the plants wiped with the WRO roller and the Hectaspan rope wick (Table 2). The fresh weights of the shoots recorded on 13 July showed that the Adville had had little effect. The other two applications resulted in plants of similar weights. As even the dead plants weighed 15-20 g these results do not fully reflect the treatment differences.

Weed beet The August visual assessment indicated that although the treated plants were showing signs of glyphosate damage there was more variation between the plants in one pot than between treatments. There were indications that the WRO roller had achieved better control than the Hectaspan, which was better than the Adville. Particularly with the Hectaspan, those parts of the beet plants above the site of deposition of most of the glyphosate were more chlorotic than the lower parts of the plants, which often remained healthy.

DISCUSSION

The results of these two pot experiments showed that the selective herbicide applicators deposited from 16 mg/g down to 0.04 mg/g of glyphosate on the target weeds (Table 1). This is equivalent to 67-0.4 mg glyphosate/plant. These loadings are in general equivalent to or higher than those expected from a conventional spray application. The differences in deposition between treatments were reflected in differences in biological activity on the potatoes and thistles but not on the docks (Fig. 2) and weed beet. The performance of glyphosate on the potatoes and thistles declined when the deposition fell below 1-2 mg/g. The docks were well controlled by all the treatments which may be related to the somewhat higher levels of deposition on this species. Weed beet tended to retain least glyphosate from all applicators and consequently it is not surprising that its biological activity was poor and erratic.

There were clear differences in performance between the three methods of application which combined the applicator with its appropriate formulation of glyphosate. The WRO prototype roller deposited the greatest amount of glyphosate on the targets and consequently caused the greatest degree of damage to the plants. In most cases they were killed. However, the observation that the gel tended to drip from the leaves of the treated plants could result in crop damage if this applicator were to be used in field conditions. It is possible that further development could overcome this problem. In contrast the Adville roller deposited the least herbicide on the weeds, which were often not controlled. There were indications that the level of deposition and subsequent control was lower when the applicator was used at the faster speed. The level of Admongel in the mixture may influence the amount of herbicide transferred from the feed to the applicator roll but no large differences in performance were noted. Larger differences resulted from difficulties in achieving uniform wetting of the applicator roll and this accounts for the poor performance of the 80 ml Admongel treatment applied in July. The Hectaspan rope-wick deposited less glyphosate on the target weeds than the WRO roller. It achieved reasonable control of docks, potatoes and thistles but the deposition on the weed beet appeared inadequate. Increased speed had little effect on its performance, unlike the Adville roller, indicating that in practice speeds up to 6 km/h could be used at weed densities similar to those used in the experiments. Angling the ropes so that they were facing downwards at 45^{o} increased the deposition of glyphosate, presumably due to increased capillary movement of the herbicide in

Fig. 1

The amount of glyphosate deposited on the artificial targets expressed as a % of that on the first one

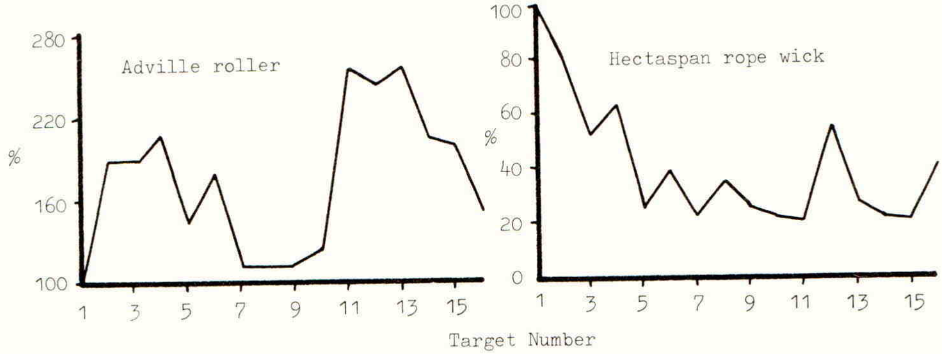
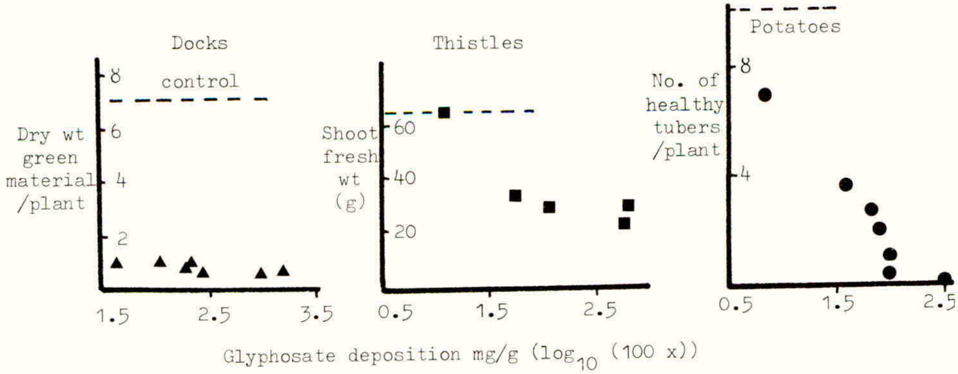


Fig. 2

The control of docks, thistles and potatoes related to the deposits on these species achieved by the applicators



the ropes. The limitations of capillary movement can also be inferred from Fig. 1 which showed that the first targets to be treated retained more glyphosate than the later ones. This may explain the drying of the ropes experienced in the field with solid nylon ropes in hot dry conditions. More recent developments with polyester over acrylic ropes seem to have increased the capillary flow (Dutt, 1981, Derting, 1981).

The data presented in Fig. 1 also show that even when the target is uniform there is a tremendous degree of variation in the level of deposition on individual targets. This indicates that the technique is likely to be unreliable. In addition there is no obvious explanation for the large differences in deposition between the two sets of thistle treatments.

Although selective herbicide applicators can deposit adequate amounts of glyphosate on the target weeds to achieve control, inadequate distribution may be the most likely cause of poor field performance. This inadequate distribution is being overcome in practice by using repeated applications in opposite directions, increasing both the total quantity of herbicide and the area of contact. The results indicate that the deposition of 10-20 mg of glyphosate/plant (1-2 mg/g).

ACKNOWLEDGEMENTS

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THE EFFECT OF AN AEROFOIL ON THE PENETRATION OF CHARGED SPRAY INTO BARLEY

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Summary The effect of an aerofoil on the penetration of charged and uncharged spray into barley was investigated in the laboratory using trays of glasshouse grown plants. The results showed that although deposits on targets increased with charged and uncharged spray when an aerofoil was used there was a problem in spray being attracted to, and deposited on, the aerofoil when the spray was charged. It was also shown that without an aerofoil charging resulted in a substantial increase in deposits on targets under a cereal canopy compared to uncharged spray. Spray, Electrostatics, Deposits, Cereals.

INTRODUCTION

A problem when spraying cereals is to get the spray down into the crop. This is important in treating diseases which may occur at the base of the crop and when applying herbicide to weeds underneath a cereal canopy. When applying electrostatically charged sprays it is often held that the spray will be preferentially attracted to the top of the cereal crop and canopy penetration will be adversely affected (Arnold & Pye, 1981).

An aerofoil mounted on a spray boom above the nozzles can deflect the air downwards and may improve penetration. This idea has been studied previously with uncharged sprays. For example Jegatheeswaran(1978) looked at the effect of an aerofoil on penetration into an artificial crop 600 mm high. He used hydraulic pressure nozzles at a pressure of 250 kPa and forward speeds of 0.8, 2.2 and 3.3 m/s. He found that without an aerofoil an increase in forward speed resulted in a decrease in spray penetration. The effect of an aerofoil at the highest forward speed was to increase the amount of spray deposited on targets in the lower regions of the artificial crop (i.e. 100 mm above ground level) by up to 25%.

Although an aerofoil improved spray penetration it was noticed that some spray usually emerged from the crop canopy after the passage of the aerofoil (Jegatheeswaran, 1982). This effect was also noticed by one of the authors when in some earlier work spray from spinning discs was blown into a cereal crop. The amount of spray emerging from the crop was not measured.

The aim of the present work was to see if the use of an aerofoil with a charged spray would result in improved deposition of spray deflected into a crop canopy.

METHODS AND MATERIALS

The arrangement of the apparatus is shown in Fig. 1.

The 2 m wide aerofoil was constructed out of folded aluminium alloy sheet. The design of the aerofoil and its position in relation to the plants was decided after trials had been carried out in a wind tunnel using smoke so that the movement of the air could be observed. Fins at each end of the aerofoil helped prevent vortices forming which could have affected the movement of the spray.

The spray was produced from three hydraulic pressure nozzles (Spraying Systems 730023) spaced 0.5 m apart. These nozzles were chosen because they produce a fine spray with a definite penetration problem. The electrostatic charging system was a development of one described by Marchant and Green (1982). Details of one of the units are shown in Fig. 2. The nozzles were operated at a pressure of 400 kPa. When the spray was charged the liquid was held at a potential of 5 kV. The charge to mass ratio of the spray was 3.0 mC/kg and the volume median drop diameter about 110 μm.

The spray solution was water plus 0.1% v:v of a non-ionic surfactant "Agral" and 0.5% w:v of a fluorescent tracer, UV39.

Winter barley (cv Igri) was sown 10 mm deep and 25 mm apart in a potting compost contained in aluminium trays 900 mm long, 90 mm wide and 40 mm deep. The trays were accommodated in a glasshouse on sand filled irrigation benches so that watering was by capillary action.

Eight trays were arranged in two groups of four, Figs. 1 and 3. The first group of trays was used as a "lead in" to avoid edge effects when collecting deposits on targets positioned in the second group of trays. The targets were thirty copper tubes 4.75 mm in diameter and 50 mm long. They were arranged in groups of three as shown in Figs. 1 and 3.

Figure 1

Lay-out of equipment, plants and targets (side view)

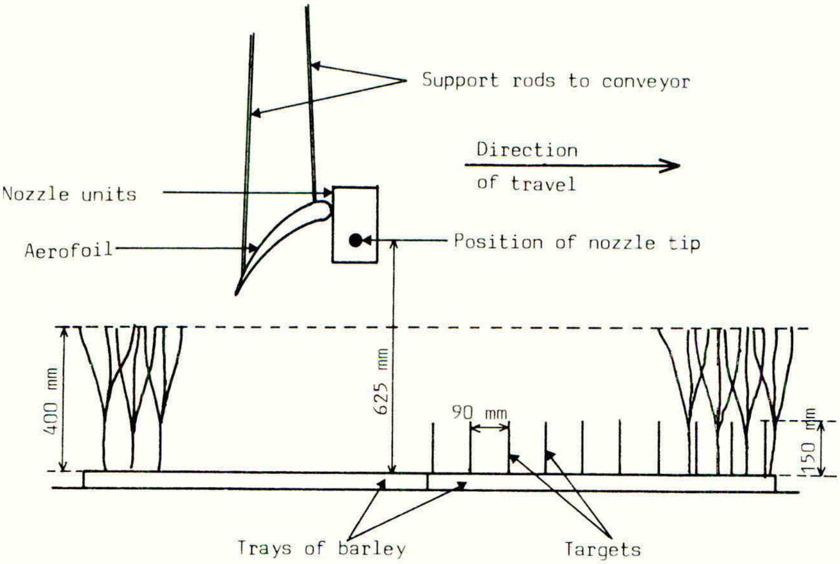


Figure 2

Electrostatic spraying system

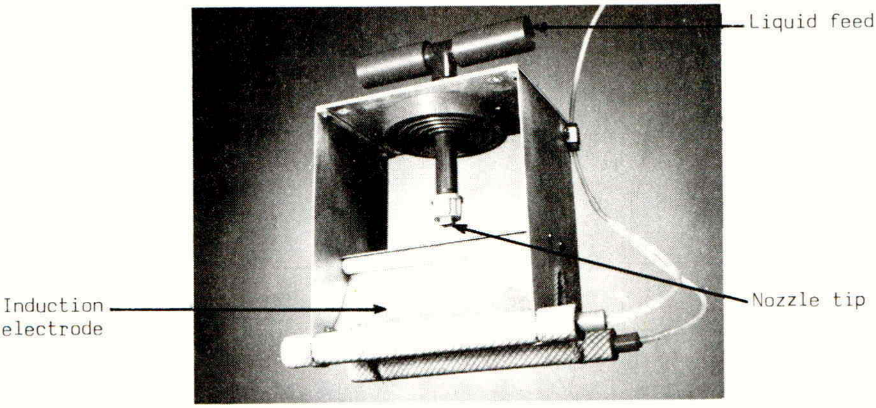
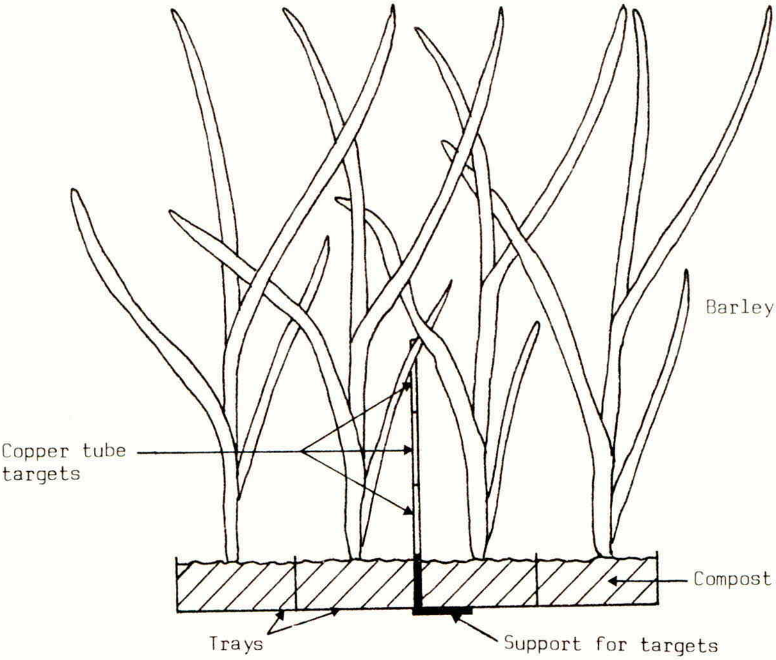


Figure 3

Arrangement of trays and targets (section - end view)



Eight runs were completed each consisting of one pass of the trays of plants. Details of the runs are given in Table 1.

Table 1

Details of experiment

Run number	Aerofoil	Charge	Forward speed, m/s
1	On	On	2
2	On	Off	2
3	On	On	4
4	On	Off	4
5	Off	On	2
6	Off	Off	2
7	Off	On	4
8	Off	Off	4

After the completion of a run the targets were removed and placed in test tubes which were then stored in the dark to prevent the fluorescent dye fading. A new set of targets was then placed on the support rods in preparation for the next run.

Because the application rate was low (about 18 l/ha at 2 m/s) it was possible to carry out all the runs with the same plants without the problem of the plants becoming excessively wet. Also the support rods for the targets being fixed in relation to the plants meant that the relationship between targets and crop cover was the same for each run. This resulted in experimental error being low thus avoiding the need for replicated runs.

After the runs were completed the amount of spray on each of the copper tubes was determined by washing off the deposits with 10 ml of water containing a surfactant (0.1% v:v Agral). The level of fluorescence of the solution was measured with a fluorimeter and from this information the amount of spray deposited on the target determined.

RESULTS AND DISCUSSION

The results are summarised in Table 2 where the mean deposits on the top, middle and bottom targets are shown for each run. Note that for runs at 4 m/s measured deposits were multiplied by two before plotting. This allowed for the reduction in application rate.

Table 2

Mean deposits on targets, μl

Run number	Target position Upper	Middle	Lower
1	0.101	0.075	0.062
2	0.085	0.067	0.064
3	0.018	0.097	0.087
4	0.162	0.121	0.098
5	0.079	0.076	0.063
6	0.034	0.021	0.024
7	0.099	0.093	0.074
8	0.062	0.048	0.047

An analysis of variance on the deposits is shown in Table 3.

Table 3

Analysis of variance

Source of variation	Degrees of freedom	Mean square x 10^6
P	2	14242 ***
A	1	69722 ***
V	1	21335 ***
C	1	13372 ***
P x A	2	2163 *
P x V	2	521 NS
A x V	1	3424 *
P x C	2	608 NS
A x C	1	41608 ***
V x C	1	8188 ***
P x A x V	2	39 NS
P x A x C	2	606 NS
P x V x C	2	1032 NS
A x V x C	1	2777 *
P x A x V x C	2	1277 NS
T	9	3029 ***
Error	207	555
Total	239	

P = vertical position of target (upper, middle or lower)
A = aerofoil (on or off)
V = nozzle speed (2 or 4 m/s)
C = charge (on or off)
T = position of target along tray (1 to 10)
Significance level: * = 5%, ** = 1%, *** = 0.1% and NS = nonsignificant

The variation in deposits on targets at different positions along a tray, significant at the 0.1% level, shows the importance of using the same trays of plants for all the runs to reduce the amount of experimental error.

Main effects of variables

The main effects of the four variables were all significant at the 0.1% level. Mean deposits on the targets are shown in Fig. 4 a-d.

Effect of vertical position of target Mean deposits on the upper, middle and lower targets are shown in Fig. 4a. There was 43% more spray deposited on the upper targets than on the lower targets.

Effect of using an aerofoil Mean deposits with and without the aerofoil are shown in Fig. 4b. 62% more was deposited on the targets when the aerofoil was used.

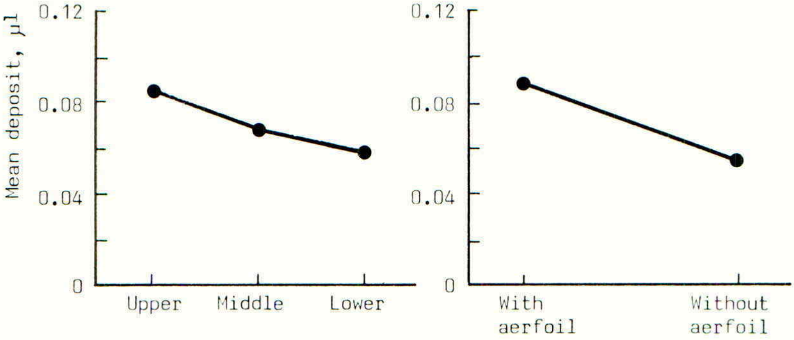
Effect of nozzle speed Mean deposits at nozzle speeds of 2 and 4 m/s are shown in Fig. 4c. The higher nozzle speed resulted in 29% more spray being deposited on the targets.

Effect of charge Mean deposits with and without a charge are shown in Fig. 4d. Charging the spray increased deposits on the targets by 23%. This shows that electrostatic attraction is effective even within a crop canopy.

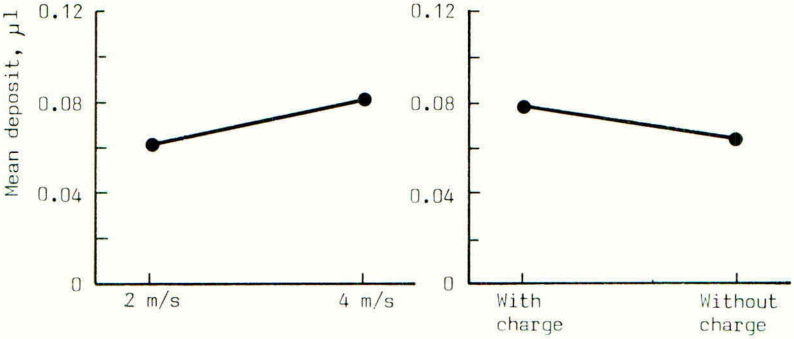
Figure 4

Main effects of variables

a) Target position   b) Aerofoil



c) Nozzle speed   d) Charge



Interaction effects of variables

Four of the first order interactions were significant at least at the 5% level. Mean deposits are shown in Fig. 5 a-d.

Effect of vertical position of target and the use of an aerofoil Mean deposits are shown in Fig. 5a. The increase in deposits on the upper targets compared with the lower targets was greatest when the aerofoil was used.

Effect of the use of an aerofoil and nozzle speed Mean deposits are shown in Fig. 5b. The increase in the deposits on the targets at the higher nozzle speed was greatest when the aerofoil was used.

An unexpected result is that deposits without the aerofoil were greater at 4 m/s. This may be because the passage of the nozzle units, which were quite bulky and close to the crop, caused movement of the crop allowing spray to penetrate.

Effect of charge and the use of an aerofoil Mean deposits are shown in Fig. 5c. With no aerofoil the effect of applying a charge was to increase deposits on the targets by about 123%. This is a substantial increase in deposit and is an important result in itself. It appears that even if spray is attracted to the top of the crop on charging, the increased attraction once the spray is beneath the canopy more than outweighs this.

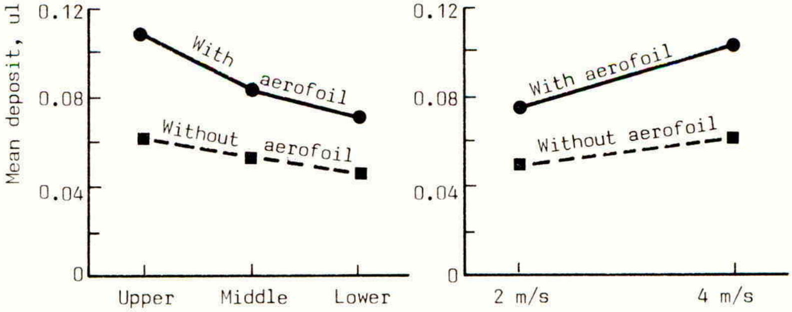
When an aerofoil was used applying a charge resulted in a reduction in deposits of about 12%. Deposits were however always greater with an aerofoil than without. The lowering of deposits on charging with an aerofoil was probably due to spray being attracted to the aerofoil. After spraying it was noticed that more spray was present on the aerofoil in the charged case than in the uncharged case.

Effect of charge and nozzle speed Mean deposits are shown in Fig. 5d. The increase in deposits on the targets when using the higher forward speed was greatest when no charge was applied. It is possible that the increased deposits measured at higher speeds are partially offset by a reduction in the space charge caused by a lowering of the application rate. This may lead to a lessening of the electrostatic attraction.

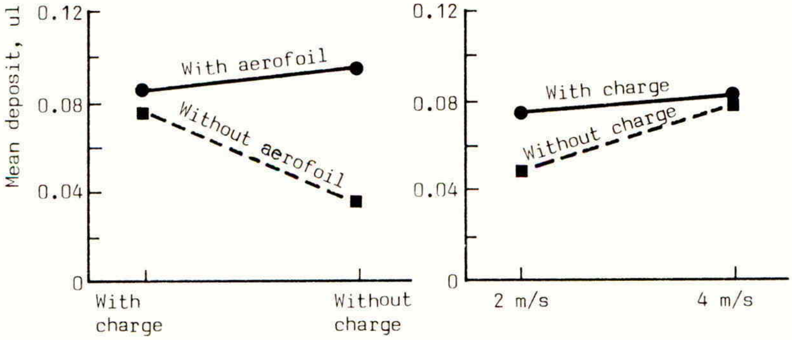
Figure 5

Interaction effects of variables

a) Aerofoil and target position b) Aerofoil and nozzle speed



c) Aerofoil and charge d) Charge and nozzle speed



CONCLUSIONS

An aerofoil used to deflect spray into a cereal crop resulted in improved deposition on targets in the lower regions of the canopy. However when using a charged spray the improvement was not so great as with an uncharged spray. This was probably because charged spray was attracted to the aerofoil. It may be possible to improve the aerodynamic and electrostatic design to overcome the problem in which case the aerofoil would be a significant advantage for charged sprays.

It was also shown that charging without the aerofoil resulted in a substantial increase in deposits on targets under a cereal canopy.

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WEED CONTROL IN ARABLE CROPS WITH THE 'ELECTRODYN' SPRAYER

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Summary. A vehicle-mounted 'Electrodyn' boom sprayer is under development to facilitate effective pesticide application in spray volumes of generally less than 5 l/ha. This is achieved through the principle of electrodynamic spraying, which allows close control of droplet size and charge. Drift is minimised and therefore spray characteristics can be optimised for contacting and acting upon the target organism.

Field trials in oil seed rape, sugar beet and cereals have demonstrated comparable weed control to that achieved by the same herbicides applied conventionally through hydraulic nozzles. Electrostatic, Electrohydrodynamic, CDA, ULV, Herbicide, Drift.

INTRODUCTION

Maximum efficacy of a pesticide can only be achieved by optimum timing and placement of its application. Economic considerations require that application be carried out effectively and at low cost. It is widely recognised that conventional, hydraulic sprayers leave much to be desired in these respects (Rutherford 1977). A basic feature of their design is a reliance on applying high volumes of water to achieve adequate efficacy. This consumes energy and time to such an extent that they may be spraying for only 50% of the time they are in use (ADAS 1976).

Weather conditions in East England during April permit safe application for only 100 hours in an average year, 50 hours in some years (Adams R J 1978). Wet soil conditions may prevent access of conventional sprayers into the field for part of that time because of weight. Thus, the limitations imposed by climate and the specialised cropping of many European arable farms make it imperative to use the time available for Autumn and Spring herbicide applications efficiently.

These considerations have encouraged a search for situations in which conventional sprayers can be effective at low volumes of application and operate at high speeds. Such situations tend to be limited to pre- or very early post-emergence timings. A more radical alternative approach to the problem has been the development of controlled droplet application systems. Whereas conventional hydraulic sprayers produce a wide range of droplet sizes, of which only a small proportion are biologically efficient, controlled droplet application systems limit the majority of the spray to a restricted range of droplet sizes. This control over droplet size allows an effective number of droplets to be produced from a smaller volume of spray.

In commercial practice rotary atomisers are used to produce droplets of limited size ranges thereby controlling the droplets' mass and, to some extent, their trajectories. When herbicides are applied, relatively large droplet sizes (>200µm) tend to be used to minimise drift. The small number of droplets of this size which can be formed from a litre of spray solution necessitates spray volumes of 20-40 l/ha in order to achieve adequate cover of the target weed in many situations.

The electrohydrodynamic atomisation process and the agricultural sprayer embodying this principle is an advanced means of controlled droplet application. Coffee (1979) describes its physical principles and highlights several potential advantages.

Two of these advantages are particularly germane to the needs of the European farmer. Firstly, droplet properties (of size and charge) can be altered continuously by changing electric field strength across the nozzle, enabling precise control to be maintained throughout the spraying operation. This facilitates maximum efficiency of application. Secondly, the spray droplets' trajectories are controlled by electrostatic as well as inertial forces. The use of electrostatic energy to reduce the drift susceptibility of spray droplets permits selection of small droplet sizes (<100μm). The advantages resulting from controlled distribution of small droplets should enable spray volumes of 5 l/ha or less to be effective when applied by 'Electrodyn' sprayer.

Field trials carried out over the past two seasons have shown that the 'Electrodyn' sprayer will achieve satisfactory weed control with herbicides applied at very low volumes. These are exemplified below.

METHODS AND MATERIALS

Eight trials are reported covering oil seed rape (2), sugarbeet (2), and cereals (4). In all trials except those reported in Tables 4 and 6, natural weed infestations were present. Treatments were arranged in randomised blocks with three replicates. Plot size was a minimum of $10m^2$.

Conventional treatments used commercial herbicide formulations diluted in 200 l/ha water. These were applied through flat-fan jets at a pressure of 200 kPa using a hand carried CO_2 pressurised spray boom.

Application by 'Electrodyn' sprayer utilised a four nozzle boom either tractor mounted or carried by two men. The purpose-designed formulations required no dilution. They were pumped by a gear-pump operating at pressures up to 167 kPa and flow rates of 0.05 to 0.3ml/sec/nozzle. Volumes of application were therefore a function of a.i. concentration in the formulation, and required dose/ha. Nozzle voltages were in the range of 20-30kV. These variables were selected manually by the operator, based upon his intended forward speed and the relationship between atomisation parameters and droplet characteristics previously determined for each formulation in the laboratory.

Crop damage was assessed either by percentage leaf area scorched or in cereals by counting the number of surviving tillers per unit area. Weed control was assessed visually as percent reduction in weed numbers or cover in the treated plots compared either with the controls, or with a pre-spray assessment of the same plot.

RESULTS

a) Winter oil seed rape

'Electrodyn' sprayer applications have been compared with conventional sprays, using pre-emergence, incorporated, treatments of trifluralin. Table 1 shows that trifluralin at 1.2kg/ha applied by 'Electrodyn' sprayer in a volume of 2.4 l/ha gave excellent control of meadow grasses (*Poa* spp) and speedwells (*Veronica* spp) and moderate control of blackgrass (*Alcopecurus*). This level of weed control was equivalent to that achieved by a conventional spray. Neither application method controlled volunteer wheat or caused visible crop injury.

Post emergence applications of fluazifop-butyl were made in early November in an adjacent trial and gave complete control of blackgrass (*Alopecurus myosuroides*) and volunteer wheat at 0.2kg/ha applied by 'Electrodyn' sprayer in 2 l/ha. Slight and transitory crop damage was produced at this dose when applied by the 'Electrodyn' sprayer.

Table 1

Effect of application method on activity of trifluralin applied pre-emergence to oil seed rape

Sprayer	Dose kg/ha	Volume l/ha	% crop injury	% weed control (165 DAT) Alopecurus myosuroides	Volunteer wheat	Poa spp	Veronica spp	Sonchus arvensis
Conventional	1.2	200	0	72	2	96	86	17
'Electrodyn'	1.2	2.4	0	72	2	96	86	17
'Electrodyn'	0.9	1.8	0	68	0	88	82	12

Table 2

Effect of application method on activity of fluazifop butyl applied post-emergence to oil seed rape

Sprayer	Dose kg/ha	Volume l/ha	% crop injury (14 DAT)	% weed control (60 DAT) Alopecurus myosuroides	Volunteer wheat	Poa spp
Conventional	0.312	200	1	100	100	10
'Electrodyn'	0.300	3.0	10	100	100	38
'Electrodyn'	0.200	2.0	5	100	100	25

b) Sugar beet

Promising results have been obtained with several sugar beet herbicides applied by 'Electrodyn' sprayer. Table 3 shows the results of a trial comparing pre-emergence applications of chloridazon. Using the 'Electrodyn' sprayer, excellent control of annual meadow grass (Poa annua) and three broad-leaved weed species was obtained at 2.4kg/ha in a volume of 6 l/ha.

Post-emergence applications of fluazifop butyl have also been evaluated in sugar beet. Table 4 shows that an 'Electrodyn' sprayer application of fluazifop butyl at 100g/ha in 0.5 l/ha volume gave near complete control of wild oat (Avena fatua), blackgrass (Alopecurus myosuroides) and volunteer barley.

Table 3

Effect of application method on pre-emergence activity of chloridazon in sugar beet

Application method	Dose kg/ha	Volume l/ha	% Crop injury	% weed control (38 DAT) Poa annua	Polygonum convolvulus	Stellaria media	Chenopodium album
Conventional	2.4	200	0	90	90	60	80
'Electrodyn'	2.4	6	0	90	90	80	90
'Electrodyn'	1.2	3	0	80	70	50	60

Table 4

Effect of application method on post-emergence activity of fluazifop butyl in sugar beet

Application method	Dose g/ha	Volume l/ha	% crop injury	% weed control (69 DAT) Avena fatua	Alopecurus myosuroides	Hordeum vulgare
Conventional	200	200	0	100	100	100
'Electrodyn'	100	0.5	0	97	94	91
'Electrodyn'	50	0.25	0	91	85	97

c) Cereals

Early post-emergence applications of chlortoluron to autumn drilled wheat have been studied. Table 5 shows that excellent control of blackgrass (Alopecurus myosuroides) and broad-leaved weeds was achieved with the 'Electrodyn' sprayer using 3.5kg/ha chlortoluron in a volume of 8.8 l/ha.

Table 5

Effect of application method on activity of chlortoluron applied early post-emergence on winter wheat

Sprayer	Herbicide	Dose kg/ha a.i.	Volume l/ha	% crop scorch	% weed control (56 DAT) Alopecurus myosuroides	Aphanes arvensis	Veronica persica
Conventional	Chlortoluron	3.5	200	3	98	100	79
'Electrodyn'	"	3.5	8.8	2	97	100	96
'Electrodyn'	"	1.75	4.4	2	63	89	17

Two trials with translocated herbicides in cereals with the 'Electrodyn' sprayer have given good weed control. Table 6 shows the volume/dose response for flamprop methyl on wild oat (Avena fatua). The 'Electrodyn' sprayer application achieved 90% weed control at 0.375kg/ha in 1.5 l/ha.

Table 6

Effect of application method on the activity of flamprop-methyl in spring wheat

Sprayer	Dose kg/ha	Volume l/ha	% injury to wheat (53 DAT)	% reduction in panicle number Avena fatua (53 DAT)
Conventional	0.5	200	0	90
Conventional	0.375	200	0	80
Conventional	0.25	200	0	80
'Electrodyn'	0.5	2	0	90
'Electrodyn'	0.375	1.5	0	90
'Electrodyn'	0.25	1	0	80

Table 7 demonstrates the performance of 'Electrodyn' sprayer with a broad-leaved weed killer, mecoprop. The 'Electrodyn' sprayer achieved excellent control of fumitory (Fumaria) and charlock (Sinapis) at 2.4kg/ha in 4 l/ha, but control of cleavers (Galium) and speedwell (Veronica) was moderate at this dose.

Table 7

Effect of application method on the activity of mecoprop in winter wheat

Sprayer	Dose kg/ha	Volume l/ha	% injury to wheat	% weed control (30 DAT)			
				Galium aparine	Fumaria officinalis	Sinapis arvensis	Veronica spp
Conventional	2.4	200	0.5	57	95	80	75
Conventional	1.2	200	0	45	85	75	55
'Electrodyn'	2.4	4.0	0	50	92	87	77
'Electrodyn'	1.2	2.0	0	40	85	82	60

In these two trials the two methods of application produced broadly similar dose responses.

A trial with ioxynil in winter wheat has shown how variation in voltage can influence performance of the 'Electrodyn' sprayer. Voltage controls directly both the size of droplet and its charge. The lower the voltage applied, the larger the droplets produced and the lower their charge to mass ratio.

Table 8 shows that spraying at the low (20kV) voltage improved the performance of the 'Electrodyn' sprayer on Shephard's purse (Capsella bursa-pastoris) in this wheat crop.

Table 8

Effect of change of voltage on activity of ioxynil octanoate applied by 'Electrodyn' sprayer

% control of Capsella bursa-pastoris (45 DAT)

Sprayer	Dose kg/ha	Volume l/ha	Nozzle voltage: 20kV	30kV
Conventional	0.8	200	100	
'Electrodyn'	0.8	2.66	88	76
'Electrodyn'	0.4	1.33	90	70

DISCUSSION

The results given in Tables 1-8 show that electrodynamic spraying of herbicides in major W.European arable crops can give weed control at least equivalent to that produced by the same herbicides applied conventionally. These levels of control were achieved against a variety of weed species, at a range of crop growth stages, using a diversity of herbicides.

In all cases, these control effects were obtained at volumes of 9 l/ha or below, and there are strong indications that 5 l/ha or less are readily achievable.

The consistently good results achieved with the 'Electrodyn' sprayer attests to the efficient deposition of spray on the soil (for pre-emergence applications) or weed (post-emergence applications), resulting from its ability to use fine droplets without unacceptable drift hazard. Another paper in this Conference (Johnston et al, 1982) deals in more detail with the control of drift afforded by the 'Electrodyn' sprayer.

Despite the efficient deposition of sprays resulting from use of the 'Electrodyn' sprayer, the results in Tables 1-8 give relatively few indications that it may permit reductions in the rates of active ingredients required. In one instance reported here, when using a poorly mobile herbicide against weeds within a dense crop canopy (ie use of ioxynil in wheat, Table 8), the 'Electrodyn' sprayer gave inferior control to that achieved conventionally. It is worth bearing in mind that the system has shown most potential for rate reduction in situations such as insect control where the pest is exposed at the top of a canopy (Morton, 1981) on which the charged nature of the spray cloud causes most deposition. In some situations weed targets may be relatively concealed by the crop canopy, which therefore acts as a stronger sink for charged droplets. Thus it is likely that the target weeds in these situations receive no more total active ingredient per plant when sprayed with the 'Electrodyn' sprayer than when sprayed conventionally.

There are signs that the performance of the 'Electrodyn' sprayer against weeds in dense crop canopies can be improved by altering the balance of the electrostatic and ballistic forces acting on the spray cloud. For instance increasing droplet inertia by spraying less highly charged, larger droplets (Table 8) has helped to improve herbicide efficacy in cereals. The use of air assistance might achieve a similar result. These aspects will be the subject of continued research in 1983.

The development of the experimental system used to obtain the results given in Tables 1-8 has been paralleled by the development of a prototype vehicle-mounted sprayer for commercial use. The sprayer consists of a fluid distribution system capable of delivering one or more separate formulations in any acceptable combination determined by the operator. Each nozzle is energised by a high voltage generator mounted immediately adjacent to it. The generators are supplied by current from the vehicle's standard electrical system. Sensors measure functions such as vehicle speed, nozzle spacing and width of boom in use. Control equipment ensures that variations in these parameters are automatically and continuously compensated for by the atomisation process, to ensure uniformly correct dose rate and optimum droplet properties.

In conclusion, the 'Electrodyn' sprayer has given weed control comparable to that achieved by conventional hydraulic sprayers. Its unique features, electrodynamic control of droplet formation, charging and propulsion permit the use of small droplets to achieve effective pesticide distribution at exceptionally low application volumes, without unacceptable drift hazard. It offers the following advantages over alternative low volume application systems:

1) Fuel savings, due to the lower requirement of energy to transport volumes less than one quarter of the lowest used at present.
2) Operational time saving, due to the elimination of the need to
   a) measure out spray concentrate, or fill spray tanks with water, and
   b) to calibrate and adjust nozzles etc.
3) Mechanical reliability, due to the absence of moving parts in the spray system, with the exception of a low pressure (fluid transfer) pump.

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PRELIMINARY TRIALS TO EXAMINE THE DRIFT OF CHARGED SPRAY DROPLETS

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Summary. The problem of obtaining a valid comparison between the drift of charged and uncharged spray droplets derived from separate sprayers but operated simultaneously in close proximity in the field (in order to obtain essentially similar meteorological conditions) has been considered. Initial tests to develop and substantiate a satisfactory technique have been recorded and the use of the technique in comparing the short range drift of charged and uncharged sprays with v.m.d.$\leq$100 µm from tractor-mounted equipment is described. Spray recovery, droplet sampling, tracer analysis, electrostatic effects.

INTRODUCTION

Considerable interest is presently focussed on methods for more precise spray placement and for control of drift of very small spray droplets. The development of a number of electrostatic spray devices (Hopkinson, 1974; Coffee, 1979; 1980) is germane to these objectives.

While aspects of the deposition of charged droplets in close proximity to a portable sprayer have been described recently by Morton (1982) and from tractor-mounted devices by Arnold and Pye (1980), the complementary facet - the drift of such droplets at close range, but beyond the immediate vicinity of the sprayer - is presently under investigation.

This report is concerned with the problems of devising an unambiguous sampling technique to monitor such charged droplet drift and provides some preliminary measurements for sprays with vmd of approximately 100 µm and below.

BACKGROUND

Effective measurement of the drift of very small spray droplets, particularly those much below 100 µm in diameter, presents a number of problems, even when the droplets do not bear a charge. Such droplets are essentially windborne and, except under unusually still conditions, deposit naturally primarily by the processes of inertial impaction and interception, with an efficiency which decreases with decreasing droplet size. Increase in wind and decrease in target dimension normal to the wind both increase collection efficiency. Sampling by means of isokinetically aspirated orifices provides a possible solution, but their use poses limitations on the scope of the sampling. Small diameter rods and cylinders (Johnstone et al., 1977) have proved satisfactory, but the use of small diameter tubing suspended vertically from tall masts (Byass and Lake, 1977; Lake et al., 1978) appears to be a more spatially effective answer. In the present work both vertically and horizontally suspended nylon cords of nominal diameter 2.0 and 3.0 mm have been used (Johnstone and Cooper, 1979; 1981), offering a compromise between the desirability of maximising collecting area, yet maintaining an adequate collection efficiency for small droplets in light wind conditions. (A 2.5 mm cord has a theoretical inertial collection efficiency of 99% for 50 µm droplets and 78% for 20 µm droplets in wind speeds of 1 m/s or greater).

For charged droplets, the electrical properties of the collector are clearly of major importance. Within the influence of the strong field surrounding the highly charged sprayer and with the spray cloud at its most dense, an earthed conducting collector would be expected to exhibit strongly enhanced collection due to charge induction, while build-up of charge due to deposition on an insulating collector might result in the converse effect. Experiments in UK with metal-braided nylon cords have illustrated the former effect (Table 1). However, in the much weaker electric fields remote from the sprayer and with the spray cloud reducing to a relatively low density, it was considered, intuitively, that an insulating collector, such as nylon cord, providing only a slow leakage electrical path to earth, would neither enhance nor inhibit the usual inertial sampling process, so that the cord system could provide a more or less direct comparison between charged and uncharged droplets. A preliminary experiment in UK to measure the drift from two hand sprayers emitting charged and uncharged droplets appeared to confirm this view, cumulative recoveries approaching 100% (Figure 1).

In the experiments reported here, carried out in Zimbabwe, comparison has been made between the drift of charged and uncharged droplets produced from two very low volume tractor-mounted boom sprayers.

METHOD AND MATERIALS

The charged droplets were produced from a tractor-mounted boom sprayer bearing six atomisers (ICI, Electrodyn system) covering a 6 m bandwidth. The uncharged droplets were produced from a tractor-mounted boom sprayer (Taurus) bearing eleven rotary atomisers (Micron, Micromax) covering an 11 m bandwidth. The sprayers were traversed through cotton, in a field of approximately 15 ha in area. Except for the northern and western margins, bordered by trees taller than 10 m, the field was surrounded by no obstruction of height greater than 5 m and upwind fetch to the headland was always greater than 100 m. Meteorological detecting and recording equipment (wind speed and direction, temperature difference) was set up in an appropriate position.

Five 6 m wooden sampling masts with support guys, were set up as indicated in Figure 2. These masts were fitted with a top spar and were rigged with halyards for raising and lowering the nylon sampling cords (effective sampling width 2.0 mm) used to effect paired vertical samples at 1, 6, 11, 21 and 41 m downwind of the nearest point of either tractor boom. Intermediate wooden posts fitted with eye screws were used to support (at the height of the top of the crop) the twin horizontal cords which were suspended along the line of the masts to sample the fall-out to the ground. On collection, these cords were divided into 5 m lengths to render manipulation easier.

A colorimetric technique was adopted for spray tracing and analysis (Johnstone, 1977). A specially formulated non-aqueous solution of either Uvitex or alternatively waxoline blue dye (10 g/l) was used for charged droplet production, while an approximately similar strength solution of croceine scarlet in water (+ 0.01% wetting agent) was used for the production of uncharged droplets. Flow rates and droplet sizes for the two sprayers were determined in preliminary calibration tests (Table 2).

In the trial, the two sprayers were traversed with atomisers set 0.4 m above the level of the top of the crop (one sprayer following immediately behind the other) along the line of the crop rows at right angles to, and immediately to windward of the line of the masts. The sprayline was approximately 100 m long centred at the sampling line and was traversed at 2 m/s a sufficient number of times to build up an analytically significant deposit (6-9 times with the Micromax sprayer and up to 20 times with the Electrodyn sprayer). The cords were then collected into small glass-stoppered bottles and taken to the laboratory for analysis. A small volume of elutant (water for the aqueous spray, xylol for the non-aqueous spray) was added to each sample bottle to dissolve the dye and the degree of absorption was then measured in a grating colorimeter (Bausch and Lomb, Minispec 20) at chosen wavelengths corresponding to optimum absorption by the tracers. (The absorption characteristics were determined by prior calibration, involving both wavelength characteristics and serial dilution to determine variation of optical density with dilution at the chosen wavelengths. The separate aqueous and oil phase extractions overcame the problem of interference between the two tracers). It was then possible to calculate the equivalent volume of spray collected on each sample from each sprayer.

RESULTS

The raw data for four separate tests (measured equivalent volume of spray per sample cord) have been converted to the dimensionless ratio of deposit per unit emission (DUE) by dividing by the volume of spray emitted in traversing a distance equal to the width of the sampling targets (2 mm) the appropriate number of times. (DUE is simply the proportion of emitted spray collected at any specific point (vertical sample), or over a sampling interval (horizontal sample)). These data, for both vertical and horizontal samples, are recorded in Table 3. The fit of data to the power law relationship:- $DUE = a\ S^b$ has been examined, where S is the distance downwind of the sampling point (or mean distance, in the case of the horizontal targets). The regression coefficients a and b together with the correlation coefficient r for the relationship have also been included in the table.

DISCUSSION

The limit of resolution of the colorimetric technique employed here occurs when the dilution is such as to give an instrumental reading of approximately 0.5% in transmission below that of the blank comparison. In terms of DUE this limit varies inversely with the number of spray passes, but because of the considerably higher output of the sprayer emitting the uncharged droplets, sprays from the latter have been determined to a higher level of sensitivity (5×10^{-4} in terms of DUE)than those of the charged droplets, where sensitivity has varied from $1\text{-}3 \times 10^{-3}$. Instrumental zero values have therefore been recorded as less than, or equal to the appropriate resolution limit.

From Table 3 it is apparent that, despite some scatter, the power law expression ($DUE = a\ S^b$) provides a reasonable approximation to the observed drift behaviour. Apart from the absence of any correlation for charged droplets in test 2 (r = 0.06 and 0.62), attributed principally to variability introduced by an inconsistent blank reading (possible insufficient extraction of the innate interfering fluorescent pigment in the cord), the correlation coefficients are generally high for charged droplets (0.81-0.97), though higher still for uncharged droplets (0.91-0.99), for both vertical and horizontal samples. The variation in the coefficients a and b between tests must be attributed to the variation in ambient conditions. Within tests, with the exception of test 2, the slope 'b' of the regression line for the charged droplets is always the steeper, as opposed to that for the uncharged droplets, implying more rapid deposition of charged droplets for both vertical and horizontal samples. However, in this instance, there is no readily apparent clear cut variation with any of the meteorological factors listed in Table 4.

In an attempt to remove some of the variation possibly associated with fluctuation in wind speed and direction, the data have been examined further in terms of a possible relation:- $DUE = a' t^{b'}$ where $t = S/\bar{u}\cos\bar{\theta}$ represents the theoretical transit time of windborne droplets between the end of the tractor boom and the mean point of the sample ($\bar{u}$ = mean wind speed at height of 2 m, $\bar{\theta}$ = mean direction of wind direction from the normal to the spray line).

The results are shown graphically in Figures 3 and 4 for vertical and horizontal targets respectively. The fit here is less good than anticipated, with r = 0.93 (0.77) for vertical (and horizontal) collection of uncharged droplets and correspondingly 0.59 (0.53) for charged droplets. It would be improved somewhat by omission of anomalous data for the charged droplets in test 2, raising r to 0.73 (0.59).

CONCLUSIONS

On the basis of tests 3 and 4 carried out with the more satisfactory colorimetric tracer (waxoline blue dye for the charged droplets) and with a higher number of spray passes to boost sensitivity, the conclusions to be drawn from the data are:-

1. (from test 3) that with droplet spectra of approximately similar size (charged droplets of vmd 90 µm, uncharged droplets of vmd 97 µm), but differing formulation (oil versus water), the resulting drift from the charged droplets is somewhat less than that from the uncharged, in terms of the proportion of emitted spray drifting or depositing beyond 20 m from the tractor boom end, in wind speeds of up to 3 m/s. As a proportion of the emitted spray, the drift beyond 40 m appears to be less than 10^{-3} for the charged droplets and less than 10^{-2} for the uncharged droplets under these conditions.

2. (from test 4) that for charged droplets of rather smaller size (vmd 51 µm) in comparison with unaltered uncharged droplets (vmd 97 µm), similar conclusions may be drawn to those in (1) above, charge having the effect of reducing the proportion of spray drifting and depositing beyond 20 m.

Future assessment work could be carried out more satisfactorily by means of a more sensitive physico-chemical tracer technique and, in a situation where suitable instrumentation is available, the clear first choice would be the use of gas-liquid chromatography, possibly using pesticide formulations themselves as tracers.

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Table 1. Deposit per unit emission on earthed and unearthed metal braided nylon cord collectors for a charged spray (vmd 75 µm) produced from a portable Electrodyn sprayer emitting 3% cypermethrin ED formulation

	DUE Collectors		
	Horizontal	Vertical	Total
Earthed	1.83	0.77	2.60
Unearthed	0.67	0.32	0.99

Note:- The two horizontal cords (5 m, metal-braided nylon) were suspended in parallel along the wind direction, 0.25 m above the ground (over short grass), one cord being earthed, the other insulated at its ends. Two similar vertical cords (6 m) were supported at the downwind end of the horizontal cords. The sprayer was carried at a height of 1 m above ground level across the direction of the wind, with the head passing over the horizontal cords at a point 1 m to leeward of the upwind end, three passes being made. Deposit was subsequently eluted and determined by GLC analysis. The unearthed collectors have accounted almost exactly for the total emission (DUE = 0.99), while the earthed collectors show enhancement by a factor of 2.6.

Table 2. Operational data for the Zimbabwe tests, including flow rates and spray droplet size

	Charged droplets				Uncharged droplets			
Test No	Passes	Flow/nozzle ml/s	nmd µm	vmd µm	Passes	Flow/nozzle ml/s	nmd µm	vmd µm
1	9	0.10	45	90	6	2.25	45	97
2	13	0.10	45	90	8	2.25	45	97
3	20	0.10	45	90	8	2.25	45	97
4	22	0.10	40	51	9	2.25	45	97

Note:- Spray potential (charged droplets) was 15.5 kV, except for T4 (27 kV).

Table 4. Meteorological data for the tests

Test No	Date	Local time hrs	$\bar{u}$ @ 2 m m/s	$\bar{\theta}$ deg	I $\sigma_u/\bar{u}$	T °C	ΔT 4.5-1.5 m °C	Ri	r.h. %
1	26/2	1219-1258	0.87	12.5	0.73	28-29	-0.44	-0.48	55-49
2	9/3	0924-1059	2.35	42.5	0.38	22-24	-0.60	-0.29	68-60
3	11/3	0714-0747	3.04	34	0.23	17-20	-0.20	-0.06	84-76
4	12/3	0658-0741	2.18	27	0.32	18-20	-0.20	-0.13	81-76

Note:- $\bar{u}$ = mean wind speed

$\bar{\theta}$ = mean deviation of wind from the direction of the sampling line

I = intensity of turbulence, expressed as the coefficient of variation of the wind

T = ambient temperature

ΔT = Temperature difference between 4.5 m and 1.5 m levels

Ri = Richardson number

r.h. = relative humidity

Table 3. Variation of deposit per unit emission (DUE) with distance from near point of sprayer (S) for charged droplets (c) and uncharged droplets (u) for four tests (1-4); mean value $\bar{x}$, standard deviation σ

VERTICAL SAMPLES

Test No	1		2		3		4		$\bar{x}$		σ	
S (m)	c	u	c	u	c	u	c	u	c	u	c	u
1	0.11	0.031	0.011	0.066	0.027	0.061	0.048	0.029	0.049	0.047	0.043	0.019
6	0.022	0.013	≤0.003	0.032	0.023	0.036	0.038	0.022	0.021	0.026	0.015	0.010
11	0.047	0.010	0.031	0.017	0.007	0.027	0.010	0.016	0.024	0.018	0.019	0.007
21	≤0.003	0.006	0.030	0.010	0.010	0.016	0.008	0.014	0.012	0.011	0.012	0.004
41	≤0.003	0.004	≤0.003	0.008	≤0.001	0.008	≤0.001	0.010	≤0.002	0.007	≤0.001	0.002
a	0.14	0.033	0.011	0.072	0.044	0.075	0.087	0.031	0.071	0.054	-	-
b	-1.0	-0.55	-0.048	-0.60	-0.76	-0.52	-0.95	-0.28	-0.73	-0.51	-	-
r	0.88	0.99	0.06	0.98	0.81	0.95	0.87	0.97	0.86	0.98	-	-

HORIZONTAL SAMPLES

Test No	1		2		3		4		$\bar{x}$		σ	
S (m)	c	u	c	u	c	u	c	u	c	u	c	u
1-6	0.022	0.024	0.024	0.029	0.015	0.030	0.041	0.017	0.026	0.025	0.011	0.006
6-11	0.018	0.013	0.018	0.014	0.010	0.015	0.013	0.010	0.015	0.013	0.004	0.002
11-16	≤0.003	0.008	0.013	0.006	≤0.001	0.013	0.010	0.006	≤0.007	0.008	0.005	0.003
16-21	≤0.003	0.007	0.024	0.005	≤0.001	0.010	0.003	0.006	≤0.008	0.007	0.011	0.002
21-26	≤0.003	0.005	0.018	0.003	≤0.001	0.006	0.003	0.006	≤0.006	0.005	0.008	0.001
26-31	≤0.003	0.005	0.018	0.002	≤0.001	0.005	≤0.001	0.006	≤0.006	0.004	0.008	0.002
31-36	≤0.003	0.004	≤0.003	0.001	≤0.001	0.004	≤0.001	0.004	≤0.002	0.003	0.001	0.002
36-41	≤0.003	0.002	≤0.003	0.0005	≤0.001	0.003	≤0.001	0.002	≤0.002	0.002	0.001	0.001
a	0.072	0.084	0.080	0.32	0.070	0.114	0.439	0.043	0.114	0.100	-	-
b	-0.96	-0.90	-0.68	-1.58	-1.28	-0.93	-1.68	-0.70	-1.01	-0.99	-	-
r	0.88	0.96	0.62	0.95	0.89	0.97	0.97	0.91	0.92	0.98	-	-

Note: a and b are the coefficients of the power law relation DUE = a S^b and r the correlation coefficient for the line of best fit.

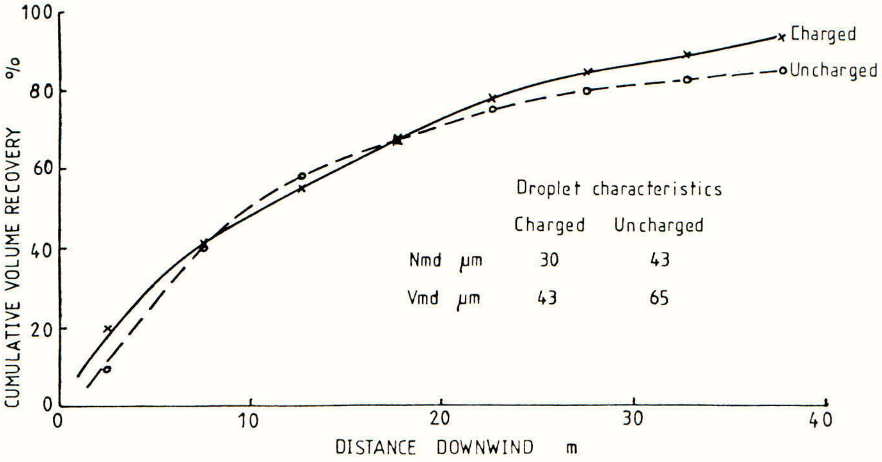

Figure 1. Preliminary experiment in UK to examine recovery of charged and uncharged droplets using two portable sprayers
($\bar{u}$ = 2 m/s)

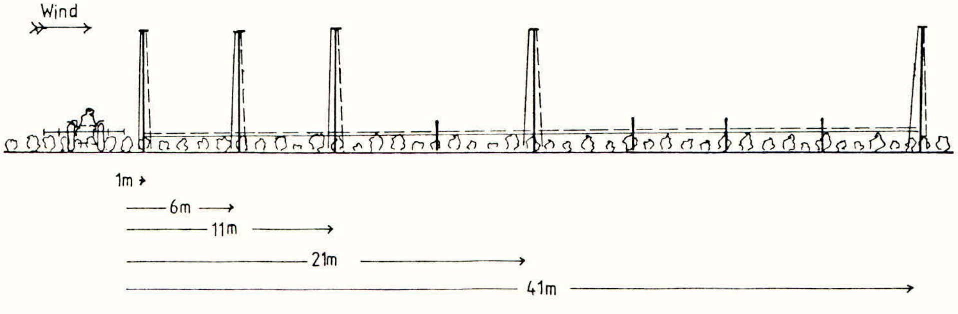

Figure 2. Sampling array for drift trial
(Five 6 m vertical masts, spaced as indicated, supporting pairs of nylon cords. Additional short masts to support pairs of horizontal cords in 5 m lengths down the layout)
Height of cotton $\simeq$ 0.75 m

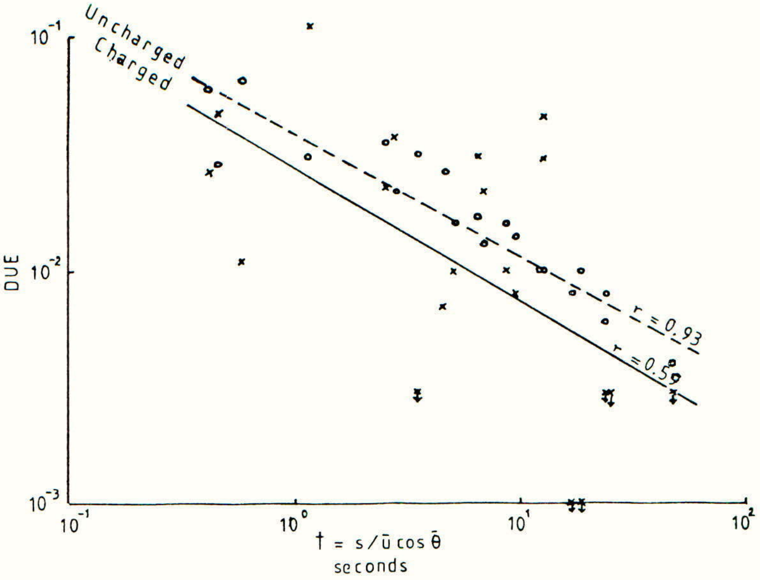

Figure 3. Variation of deposit per unit emission (DUE) with theoretical droplet flight time (t). Vertical cord samplers

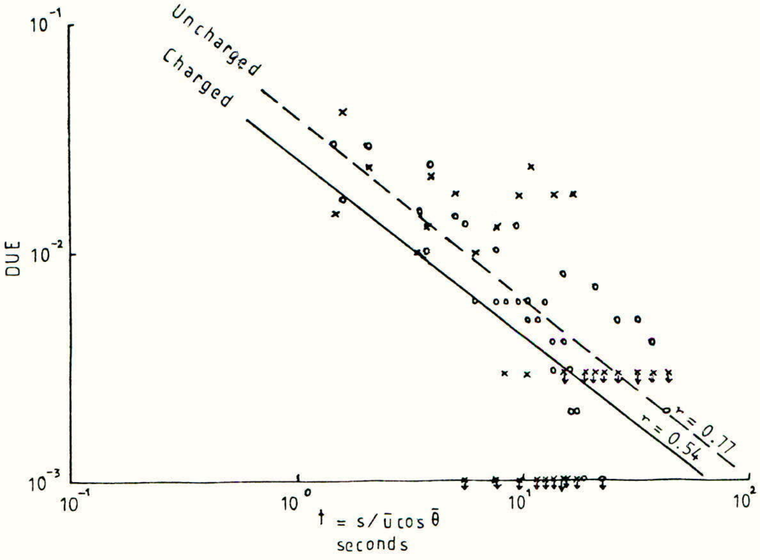

Figure 4. Variation of deposit per unit emission (DUE) with theoretical droplet flight time (t). Horizontal cord samplers

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THE PRINCIPLES OF AND NEW DEVELOPMENTS IN ULV SPRAYING : SOME REFLECTIONS

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Summary: Experience in Ultra Low Volume spraying, with non-evaporating carrier liquids with even sized droplets, has shown that a very much greater percentage of chemical applied is collected by the target surface than with conventional spraying. Critical examination should be done to show whether with this method recommended dosage rates can be drastically cut and whether Ultra Low Volume spraying, can, in future, be synonymous with Ultra Low Dosage spraying. Keywords: CDA (Controlled Droplet Application), Deposition, Dispersion, Efficiency, Electrostatics, ULV (Ultra Low Volume)

In my paper at Brighton in 1969 I stated that: "The efficiency of a spraying machine is inversely proportional to the range of droplets it emits, whilst the suitability for a specific problem depends on the actual size of the droplets emitted" and on the basis of this I suggested various ideas for basic research to improve the efficiency of pesticide application.

It would seem that over a decade later the need for such research is still not fully recognised. Traditional spraying methods are assumed to be efficient because they are sufficient, a logical fallacy of the first order. Indeed hydraulic spraying is only sufficient because it is inefficient - because it covers a vast range of droplet sizes and trajectories, only a few of which are actually producing the intended effect.

Efficiency is: "the ratio of useful work performed to the total energy expended". The saving of pesticide costs through increased efficiency (a 1% increase resulting in an annual saving of $120m at present) would at least be equalled by the other savings. Logistical savings are potentially enormous and have resulted in the uptake of CDA in some developed farming systems already; environmental pollution (and it is probably instructive to think of all pesticide application as the contamination of our environment) can also be reduced, etc.

Thus enormous savings are possible with increases in spraying efficiency but where are these savings to be made? Every spray application has 3 phases:-

a) cartage and atomisation of the spray liquid;
b) dispersion and deposition of the spray;
c) effectiveness of the spray deposit i.e. of the spray application.

To quote again from my 1969 paper: "Because it is obvious that if the recommended dose of pesticide, diluted or undiluted, were dumped on one spot in the middle of the area to be treated, no beneficial results could be expected, we have come to assume that we should distribute the material uniformly over the target. It is, however, much less obvious that spraying a crop with droplets of indiscriminate size can be nearly as wasteful".

Effectiveness of the pesticide must depend on the amount that reaches the target and then on the evenness of distribution on the target.

Very simple calculation shows that minute quantities of liquid, if evenly distributed, can cover vast areas e.g. 1 litre applied in 70 μm droplets over

1 hectare of surface gives a theoretical droplet density of over 55 droplets/cm^2. It would again seem logical, particularly in insecticide and fungicide spraying, that the greater the droplet density (provided a certain, at present undefined, minimum level of pesticide is present in each droplet) the greater the possibility of control and this would suggest a move towards the smallest droplet possible (which, I believe, would also be better taken up by the insect or plant). The relationship between droplet size and chemical dosage (i.e. droplet volume) is a cube one - 500 µm droplets are not just 10 times the size of 50 µm droplets, they are 1000 times the volume, meaning that if the latter droplets contain the right amount of pesticide for the target, the former will contain 1000 doses, 999 of which will be wasted if this droplet hits the target. Thus if we had a spray of which half was 50 µm droplets, the optimum size for the target, and half 500 µm droplets, all of these droplets hitting the target, we would still be wasting 99% of this spray (and a sprayer capable of producing these spray characteristics, with a vmd/nmd ratio of under 2, is quite good compared with present hydraulic sprayers, where vmd/nmd ratios often exceed 10).

Theory has unfortunately lagged far behind practice, CDA machinery manufacturers compromising by making machines which produce a droplet size that works (rather than the optimum) for specific targets, within the constraints of producing a tool that farmers can use, especially peasant farmers in the Third World who should be the most important sector of world agriculture. In the underdeveloped countries hydraulic sprayers are not even sufficient in many instances, simply because peasant farmers cannot afford to use them with their high chemical and huge water requirements. The adoption of CDA techniques worldwide is the practical answer to those who doubt the efficiency gains possible through CDA which has already revolutionised crop spraying practices by allowing spraying to be undertaken at all in certain areas.

However, there is doubtless a truly Biological Optimum Droplet Size for any particular pesticide application, which must of necessity be linked to chemical formulation and concentration as two of the other major factors. My maxim for the past 20 years has been: "if it doesn't work - use less", the reasons for which have been empirical observation and instinct, but this idea was at least partially confirmed by research done last year by Nigel Scopes and David Munthali at the G.C.R.I. Their results question the very principles on which our present spraying practices are based, showing, in the particular work undertaken, that reductions in droplet size on the leaf dramatically reduced the amount of chemical required to kill red spider mite and white flies. Chemical concentration and formulation were also shown to have dramatic effects on the efficiency of the pesticides (see Figure 1).

Because of the cube relationship between droplet size and chemical dosage if smaller droplets are indeed more efficient we might well be on the threshold of huge savings in the amount of pesticide we need to apply to the environment. The use of even sized small droplets would also obviate the need to cart to the field huge volumes of pesticide and diluent to act as a carrier for pesticides, which in the case of water only then evaporates, leaving tiny chemical dust particles from the millions of very small droplets produced by present hydraulic sprayers which are then subject to uncontrolled drift. A study showing the advantage of CDA over conventional spraying in preventing uncontrolled drift using water as the carrier was a trial at Cornell University in the USA comparing the damage on tomato plants downwind from the application points of a Micromax rotary atomiser and a conventional nozzle spraying 2,4-D (see Table A).

The folly of using water as a carrier was shown very clearly in a comparison done by the Forestry Commission, spraying pine beauty moth with fenitrothion from the air, with LV (at 20 l/ha water based) and ULV (at 1 l/ha oil based), as shown in Table B. To quote at length from this report: "In the case of the LV spray, the amount of fenitrothion and the number of droplets collected by the pine needles suggest that all droplets less than 120 µm in diameter lost all their water by evaporation and probably failed to impact on the needles. These droplets represented about 20% of the total volume applied ..... The trial showed clearly that there is no advantage in LV spraying whereby the volume rate of application is increased 20 times by adding water. The evaporation of water from small droplets results in loss of chemical outside the target area and the presence of big droplets due to a coarsening of the vmd resulted in greater ground deposit ..... Analysis of chemical collection by pine needles showed that those exposed to ULV rates collected nearly 75 percent more active ingredient than those exposed to LV rates (590 ng compared with 1030 ng per needle) the larvae in the ULV plots collected three times as much active ingredient as those in the LV plots (1285 ng compared with 409 ng/g larvae). The amount of chemical lost to the ground was over 8 times greater in the LV compared with the ULV sprayed plot (13.5 compared with 115 g/ha) ..... Spraying at ULV rates was better than at LV rates in all respects. ULV in this trial is synonymous with CDA (controlled droplet application)."

All chemicals should be formulated with oil (or an anti-evaporant) to ensure that droplets retain their size between atomisation and deposition (and oil based formulations may also, I believe, show an enhancement of biological effect, spreading better and being taken up more easily by plants and pests, along with better retention) and this must be the case if we are talking about small droplets (when speaking of small droplets I mean those under 30 µm) where the water carrier would evaporate totally in fractions of a second.

However, if we want to use droplets under 30 µm we run into problems with deposition. The choice of droplet sizes for our spinning disc sprayers has been influenced by the desire to ensure that farmers could utilise the massive, and free, natural forces of wind and gravity to disperse and deposit their spray. However, this imposes a lower limitation on the droplet size of approximately 30 µm with insecticides and fungicides since sufficient energy could not be imparted to these droplets to impact them on targets other than flying insects (who provide their own collection energy) or very small and/or hairy surfaces, such as the pine needles mentioned above, and approximately 150 µm droplets with herbicides since these would otherwise be subject to drift.

Therefore, to utilise droplets below these sizes we require an artificial force to deposit them. An air blast is useless because it is not only energy intensive but it is dissipated within a very short distance (stand only 100 yards behind a jet airliner if you don't believe me). Electrostatics is a theoretically perfect answer, and is qualitatively different from other systems of deposition, in that the droplets' energy is internal, rather than being provided by some external force applied to it, and can thus deposit on any surface. However, electrostatics, a depositional force, actually works against spray dispersion in that the droplet will tend to impact on the first surface exposed to it in a strong electrostatic field, leading to a lack of penetration, aggravated by the forces of wind and gravity with larger droplets. This may well be an advantage for some systemic herbicides which demand placement spraying, although some problems might arise in post-emergent applications, but is a serious drawback for spraying insecticides and fungicides (except in those rare cases where no penetration is required e.g. mildew on apples or blister blight on tea).

These penetration problems have been shown to exist with ICI's present Electrodyn sprayer and lack of dispersal of the spray has also led to a drastically reduced swath width (and therefore workrate) compared with the Ulva. However, as stated above, the use of large droplets aggravates these problems so once again this appears to indicate the need for smaller droplets in insecticide and fungicide application which will be transported through the crop by wind (the force of gravity being negligible in the case of these small droplets) until they come close enough (probably a matter of mm) to a target surface to be attracted and deposited. Where spray dispersal is not required, the replacement of gravity with electrostatics will also allow the use of smaller droplets; the Forestry Commission already having shown that small herbicide droplets can be very effective.

It would thus seem that smaller, even sized droplets, electrostatically charged if we wish to go below a certain droplet size, may provide a way forward for pesticide application. So how do we produce these droplets?

The traditional hydraulic nozzle is not only inefficient, requiring considerable energy to atomise spray liquid from its stationary surfaces due to the high surface tension forces involved, but is also highly inaccurate, forming droplets by the random disintegration of a liquid sheet. Although liquid properties can be altered to promote better atomisation, the inherent disadvantages of this system mean that it will always be largely inaccurate and produce a vast range of droplet sizes, and thus whether it is worthwhile attempting to apply electrostatics to such a nozzle to create charged droplets is arguable, especially given the practical difficulties involved.

So far the only practicable mechanical means of producing relatively even sized droplets has been rotary atomisation, where the liquid's surface tension is overcome at the disc's periphery by the centrifugal force created by the disc's rotation. Droplet size can be altered by changing the disc speed (of which it is a direct function) and also by changing the flow rate onto the disc, due to the advent of controlled atomisation by the use of teeth as zero-issuing points, and individual feed channels to each tooth. Ligament atomisation is preferable (although not quite so accurate as direct droplet formation) due to the lower energy requirement, with the same feed rate producing smaller droplets, as I have outlined in previous papers.

However, the application of electrostatics to spinning discs requires careful study since the forces of rotary atomisation and electrostatic atomisation of a charged liquid have proved to be quite independent in our experience. Thus unless a balance can be struck these forces can end up producing a wider droplet spectrum than the utilisation of rotary atomisation alone, and we would thus move away from the idea of CDA, although obviously some of the waste due to this uneven atomisation may be offset by enhanced deposition on some surfaces with charged droplets (although penetration may again be a problem with larger droplets).

The last 3 years have seen the advent of a revolutionary new system - the Electrodyn - invented by Dr. Ron Coffee of ICI. This not only produces charged droplets but also atomises purely by electrostatics with a very low power requirement (obviously the neatest solution to the whole problem) although specially formulated liquids of a particular resistivity are required to optimise the system. The main disadvantage of this system, as far as I can see, is the fact that the electrostatic field used to create the droplets is so strong that it also deposits the droplets immediately. This is aggravated by the fact that in practice the machine has been set to produce droplets of an equivalent size to the Ulva (approximately 70 µm) which was a choice intended for a completely different mode of deposition, and shows the problems of lack of penetration and low swath width. The use of another energy source to remove the droplets from the atomising electrostatic field by imparting to them an initial velocity (possibly by either an air blast or by a spinning disc) could prove to be an advantage for spray dispersion. Correct droplet dispersion and deposition requires a careful balancing of the forces acting on the spray droplet. In the past we had wind and gravity providing constant forces on the droplet (the artificial forces involved in droplet creation again being dissipated rapidly e.g. a 70 µm droplet leaving the edge of an Ulva disc at over 100 km/h loses all of this initial velocity within the first 15 cm of its flight path). Wind gives a constant 1-10 km/h lateral velocity, gravity a terminal vertical velocity dependent on the droplet size (e.g. a 70 µm droplet has an approximate terminal velocity of 15 cm/s, a 250 µm droplet one of 95 cm/s). Wind is always the force of dispersion; a combination of wind and gravity (which is predominant being determined by the droplet size involved) is the force of deposition. However, as stated, these forces cannot impart sufficient energy to impact droplets under 30 µm. Electrostatics allows us to deposit these droplets but, as outlined, can actually hinder dispersion. Thus, for these small droplets, we must balance wind and electrostatics as the forces of dispersion and deposition respectively, whereas for larger droplets, where gravity must be taken into account, we need to balance three forces - always a difficult task.

Thus electrostatics offers a great potential, but not as the sole force for atomisation, dispersion, and deposition of a spray, but as part of a balanced spray application. With small droplets wind will remain the predominant force of spray dispersion; the use of a cloud of charged droplets depositing due to image and space charges when sufficiently close to the target providing a possible means of drastically improving spraying efficiency with insecticides and fungicides. The use of smaller droplets with herbicides also promises massive potential savings.

I hope that the next decade will show a much greater understanding of the principles of ULV spraying and the need for basic research to improve the efficiency of pesticide application, not just to cut costs but to save lives by ensuring that all the world's farmers can protect their crops and in so doing protect their peoples from the threat of starvation. To do this we need to further pesticide application as a science, rather than the random process that it is at present. Moreover, we need to make any advances in technology available to all farmers which means that we must develop simple machines with lower power requirements, with preformulated chemicals supplied by the chemical manufacturers to ensure the enhanced efficiency and safety of pesticides, so that in the future we do not provide litres of poison to be randomly applied but rather hectares of crop protection; an overall concept for a complete operation.

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FIG 1 Dicofol concentration v T urticae egg mortality at constant droplet dia..

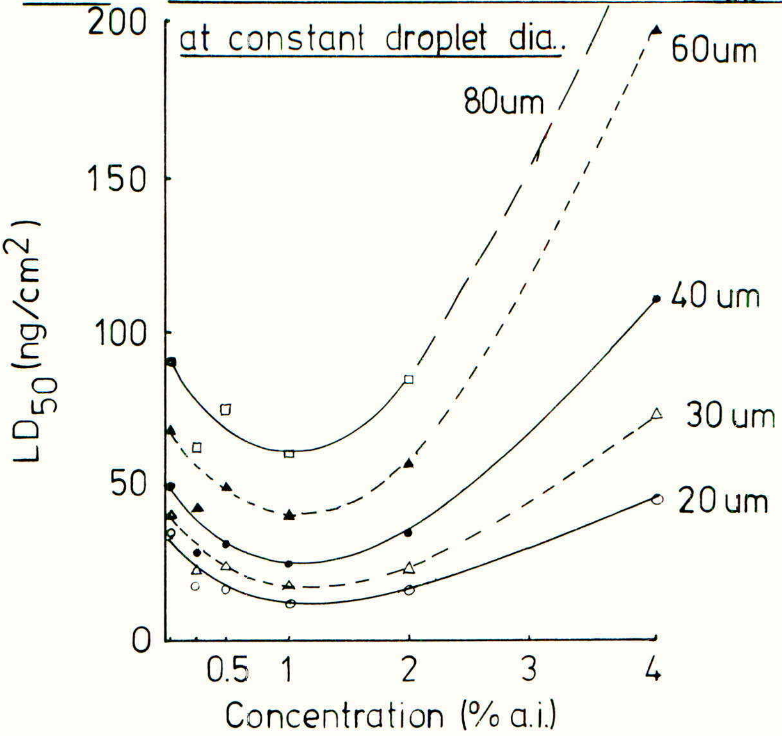

TABLE A

Tomato Drift Experiment (2,4-D): Micromax v. Pressure Nozzles
Injury rating 0-10 (death), 4 days after spraying, average over 3 replicates
in a) wind speed 3-5mph; b) wind speed 10-15mph

	Distance from sprayer (ft)									
	5	10	15	20	30	40	60	90	120	180
a) Micromax	0	0	0	0	0	0	0	0	0	0
a) Pressure Nozzles	5.67	5.33	4.33	5.67	6.33	1.33	0	0	0	0
b) Micromax	6.33	0	0	0	0	0	0	0	0	0
b) Pressure Nozzles	8.00	7.33	4.67	4.33	4.67	4.00	5.67	0	0	0

TABLE B

Aerial Spraying against P.flammea: The Fate of the Fenitrothion Applied

	ULV	LV
Applied	300	300
Lost outside target area	3	60
Lost to ground	13.5	115
Collected by target surface	283.5	125
Percentage collected by targets	94.5	41.7

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THE QUANTIFICATION OF SPRAY DROP DRIFT

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Summary A random-walk model of atmospheric diffusion has been modified and applied to the simulation of the drift of evaporating, sedimenting spray drops. Drop size, wind speed, rate of evaporation, height of release, atmospheric turbulence, and whether or not the drops are collected with 100% efficiency by the underlying surface are factors which are demonstrated to interact strongly in their control of drop drift and deposition. Examples are given showing the influence of release height and evaporation on drop deposit densities for a range of meteorological conditions. Random-walk, model, drops, drift, deposition, evaporation, wind speed, turbulence, stability, reflection.

INTRODUCTION

Many factors contribute to the movement of spray drops and the subsequent deposit of some of them outside their intended target area. Most important are (a) the size spectrum of the emitted drops, (b) the height distribution of each drop size fraction when the drops have decelerated from their initially high ejection speeds to speeds where their subsequent trajectories are controlled solely by settling velocity and atmospheric flows, (c) wind speed and atmospheric turbulence, (d) the rate of evaporation of the drifting drops and (e) the collection efficiencies of the underlying surface for the range of drop sizes involved. Some of these factors may interact: for example (b) (and to a lesser extent (a)) are linked to wind speed (c) (Courshee 1959; Yeo 1959). These interactions usually prevent the use of results from limited numbers of field experiments in deriving reliable general expressions for estimating drift.

An inherently better method of quantifying drift (and which is also much less expensive than comprehensive field experiments) is to construct physical models of the various processes contributing to drift, and then to verify that the models are able to produce results in fair agreement with those from a limited number of field experiments. The models' physical bases then allow their use in estimating drift over a wide range of meteorological conditions. A shortcoming of this approach when applied to hydraulic sprayers is that at present there appears to be no method of estimating accurately, for particular boom height and wind speed, the effective release heights of the various drop size fractions. The spray liquid, after ejection at speeds typically around 20 ms^{-1}, entrains air as it breaks up into drops and this allows the drops to travel further before decelerating to their settling speeds than would drops ejected singly. The increase in stopping distance caused by the entrained air is not constant, but is a function of drop size and airspeed relative to the boom. Arbitrary release heights will be assumed in the present paper in the absence of a satisfactory model of this process.

Theoretical treatments of the drift and deposit of drops released at a known height are certainly not new. Those most widely reported are ballistic, Gaussian-plume (K-theory) models (e.g. Bache and Sayer, 1975 ; Dumbauld et al, 1976) in which the released drops are assumed to diffuse vertically, and sediment, to form an inclined plume whose vertical dimension at different distances downwind is related to atmospheric stability. The calculated drift deposits follow immediately from the geometry of the intersection of plume and crop or ground surface. Even uncomplicated versions of such models can give useful results, but they are not well-suited to exploring the consequences of drop evaporation, or of partial reflection of small drops at the surface.

An entirely different method of modelling drift will be presented in this paper. It is adapted from a "random-walk" model of atmospheric diffusion (Ley, 1982) which has been shown to give good results when applied to neutrally - buoyant particles. The method is used to explore the effects of release height, wind speed, atmospheric stability, evaporation and collection efficiency of the underlying surface on drift, and drift deposit.

THE RANDOM-WALK MODEL

The model assumes that the trajectories of individual drops, away from the immediate influence of the spraying system, can be represented by a connected series of discrete displacements. The size of each displacement is determined by the mean wind speed (including its variation with height above ground), the characteristics of the atmospheric turbulence, drop settling velocity and the length of the time-step over which each displacement is calculated. The broad details of simple random-walk models suitable for representing the effects of atmospheric turbulence have been described by Hall (1975). Considering for the moment the vertical component of drop motion (the treatment is readily extended to three dimensions), Hall showed that the most satisfactory representation assumed that the velocity w_{i+1} at any time step i+1 in the simulation is related to the velocity at the previous time step, but with the addition of a random component r and the fallspeed of the drop v_s. Thus

$$w_{i+1} = \alpha w_i + r - v_{s_{i+1}} + \alpha v_{s_i} \qquad (1)$$

α (< 1) is related to the scale of turbulence in the atmosphere, and increases with height above surface and increasing atmospheric instability. It is inversely related to the length of the time step. Hence, for a given time step, the persistence of drop velocity is largest in unstable conditions, and when well above the surface. The size of the random component r is directly related to the magnitude of atmospheric turbulence.

In the case of horizontal motion it is the alongwind component (u_i) which is of most importance in the context of drift: crosswind diffusion of drops is only of minor interest when the sprayed area has a crosswind width of several hundred metres. The position after n time-steps of a drop released at an origin x = o, z = h (x measured downwind, z vertically upward) is then

$$(x,z) = (\sum_{i=1}^{n} u_i \Delta t_i \text{ , } h + \sum_{i=1}^{n} w_i \Delta t_i \qquad (2)$$

where Δt_i is the length of the time step. Evaluation of the various terms in eq(2) is carried out using eq(1), and a corresponding equation for the alongwind velocity component: micrometeorological theory is used to derive the necessary quantities for typical daytime conditions (Thompson et al, 1982).

The drops are assumed to be water-based, containing initially 1% of pesticide whose specific gravity is for convenience set equal to 1. The treatment of drop evaporation is simplified by assuming that this takes place as if the drops are pure water, until only the active ingredient remains: this appears to be a satisfactory approximation in many cases (Wanner, 1980). On this basis the temperature of the drop is close to the wet-bulb temperature of the air (Ranz and Marshall 1952), so the vapour pressure difference (saturation vapour pressure at drop surface minus vapour pressure of the surrounding air) is

$$\Delta p = 67 \times \text{wet-bulb depression in deg.C} \quad \text{(Pascals)} \tag{3}$$

Mass-transfer theory (e.g. Ranz and Marshall, 1952) may then be used to calculate the rate of change of drop diameter (d) with time: the required expression is

$$\frac{d}{dt} d = - \frac{0.36\, \Delta p}{d} \left(2 + 0.12\, (v_s\, d)^{1/2}\right) \tag{4}$$

: the drop diameter is measured here in microns. Eg. (4) is used to calculate the new drop diameter at the beginning of each time step, and the corresponding value of settling velocity is then determined.

An important aspect of the model is the treatment of impaction of drops on the underlying surface. Experimental data (e.g. Lawson and Uk, 1979) confirm that very small drops are partially reflected at the surface: the reflection coefficient is larger for smooth surfaces (e.g. bare soil) than for rough surfaces (e.g. a mature cereal crop). Physical considerations indicate that the reflection coefficient will be a function of wind speed also. The model was used with either the assumption that drops were completely absorbed on the surface at their first impact, or were partially reflected, with the reflection coefficient increasing from zero for drops of 100µm and larger, to 0.95 for 10µm drops: any dependence on wind speed for the coefficient was ignored because of uncertainty as to how it should be quantified.

RESULTS AND DISCUSSION

Simulation of drop trajectories were carried out for the following variable values:

Wind speed at 10 m	2, 5, 10 m/s
Crop height	0.2, 1.0 m
Effective release height above crop	0.2, 0.5, 1.0 m
Initial drop sizes	50, 100, 150, 200µm
Relative humidity	100%, 50% at 20 deg.C
Weather	Overcast, (near-neutral stability), or bright sunshine (unstable)

Trajectories were calculated up to 1 km from the release point; it was necessary to follow the trajectories of up to 10 000 individual drops in each of the cases defined by combination of the variable values above in order to reduce the statistical variability of the calculated deposits at the longer distance to a level where reliable smooth curves of deposit density against distance could be drawn. These calculations involved around 100 sec time on a high-speed computer (IBM 360/195) for each set of trajectories, demonstrating a major drawback of the model, which is its large demands on computer time.

It is not possible to discuss here more than a small proportion of the several hundreds sets of results which have been obtained. Of most interest are the results for smaller drops (100µm and less) since significant drift for drops of 150µm size or larger occurs only in stronger winds - force 4 and above - or with effective release heights of 1 m or more in lighter winds, corresponding to boom heights of at least 1.5 m above the crop surface.

Table 1 shows the effects of release height and atmospheric stability on deposit densities of non-evaporating 100µm drops, which are assumed to be completely absorbed when they first penetrate the crop canopy. The results are expressed as average numbers deposited per square metre at different distance downwind from a crosswind line source emitting 10 000 drops per metre of line. The deposits are seen to fall off rapidly with increasing distance, becoming roughly proportional to x^{-2} at large distances. Increasing the release height increases the deposit in roughly the same proportion. Substantially larger deposits are found at larger distances in cases where the atmosphere is unstable, but even here the number of drops remaining airborne at 500 m is very small.

Table 1

Deposit densities for non-evaporating drops of 100μm diameter (wind speed = 5m/s)

Effective release height(m)	Atmospheric stability	Deposit densities (drops/m^2) at:				Drops still airborne at 500 m (%)
		10m	50m	100m	500m	
0.2	neutral	80	1.3	0.23	0.005	< 0.1
	unstable	100	2.9	0.6	0.02	0.2
0.5	neutral	260	4.4	0.9	0.02	0.1
	unstable	280	9	2.0	0.09	0.5
1.0	neutral	500	12	2.0	0.03	0.2
	unstable	420	22	3.0	0.20	1.4

The corresponding results for evaporating drops are given in Table 2. Here those drops remaining airborne for more than about 20 s will lose all their water and decrease in size to about 20μm. Such small drops are unlikely to be collected by the crop without partial reflection: results in the Table are given for a reflection coefficient increasing from zero for 100μm drops to 0.9 for 20μm drops, and also for a zero reflection coefficient for all sizes. A comparison with the previous Table shows that the reduction in fall speed of the drops following evaporation produces a substantial increase in the numbers remaining airborne, and a several-fold increase in deposit densities at the larger distances. At shorter distances ($\lesssim$ 50m) such a comparison produces a less clear-cut outcome, demonstrating the complexity of the interacting effects of drop fall speed, release height, atmospheric stability and wind speed.

The results in Table 2 indicate an unexpectedly small effect on deposit densities when the reflection coefficient for the smaller drops is increased from zero to close to unity. The final column of the Table shows that a consequence of the increased reflection coefficient is a larger number of drops (about 50% more) still airborne at 500m. This increase in drop numbers would be completely inadequate to compensate for a large reflection coefficient ($\simeq$ 0.9) if the additional (reflected) airborne drops were distributed in the vertical in the same way as the unreflected ones. However, when drops are reflected they are likely to remain close to the surface for some time (and possibly undergo further partial reflections) because of the small scale of atmospheric turbulence near the surface. The reflected drops therefore produce a substantial increase in the average numbers fairly close to the surface at any time, and in terms of deposit densities this appears to largely compensate for the high reflection coefficient. Some vertical profiles of airborne drops obtained by Lawson and Uk (1979) support this idea. Closer to the source the results in the Table, and those plotted in Figure 1, demonstrate that a non-zero reflection coefficient for the small drops causes a significant reduction in the surface deposit. This is because at these distances few of the airborne drops have been reflected, so that drop numbers near the surface are similar, whether or not partial reflection is taking place.

Calculations for drops with 50μm initial diameter show effects of release height and atmospheric stability on deposit densities which are similar to those for

Table 2

Deposit densities for evaporating drops @ 100μm initial diameter (wind speed = 5m/s)

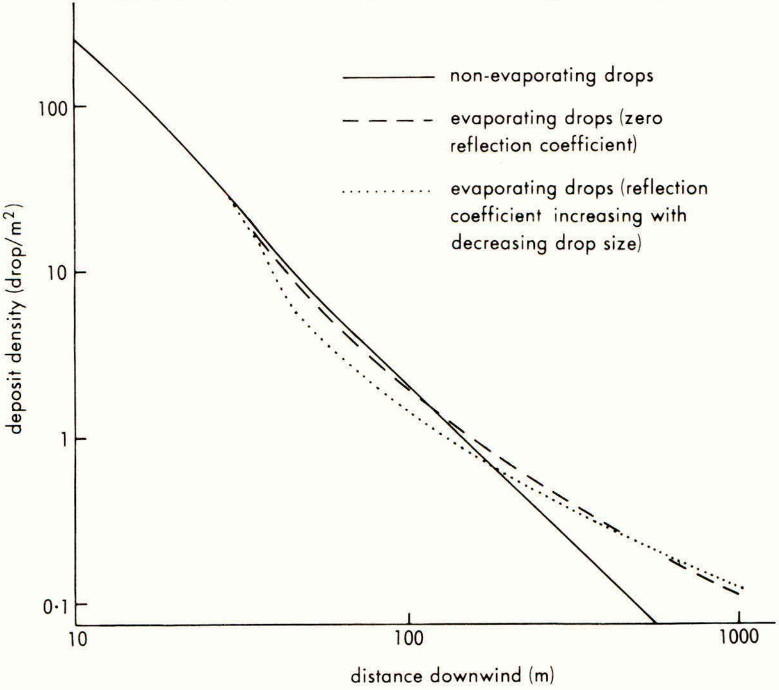
Release height(m)	Atmospheric stability	Deposit density (drops/m^2) at:				Drops still airborne at 500m(%)
		10m	50m	100m	500m	
0.2	Neutral[a]	80	1.8	0.6	0.04	1.0
	Neutral[b]	80	1.4	0.5	0.06	1.9
	Unstable[a]	95	3.0	0.9	0.08	2.0
	Unstable[b]	120	2.1	0.7	0.07	3.0
0.5	Neutral[a]	280	7	1.8	0.17	3.1
	Neutral[b]	280	4.2	1.3	0.10	5.3
	Unstable[a]	260	7	2.2	0.25	5.4
	Unstable[b]	250	5	1.7	0.24	8.4
1.0	Neutral[a]	400	16	4.6	0.40	8.4
	Neutral[b]	400	9	3.7	0.45	13.0
	Unstable[a]	380	16	4.6	0.5	11.4
	Unstable[b]	370	9	3.8	0.6	17.5

a: zero reflection coefficient for all drop sizes

b: reflection coefficient increasing from 0 (100μm drops) to 0.9 (20μm drops)

Fig. 1

Deposit densities for evaporating and non-evaporating drops (100μm diameter initially) released 0.5 m above a crop in unstable conditions, with wind speed at 10 m height of 5 m/s



100μm drops. However, the small settling speed of 50μm drops leads to greater drift, but also to a smaller increase in drift when the drops evaporate since in all but very light winds the typical vertical turbulent velocities of the air are significantly larger than drop settling speeds.

CONCLUSIONS

The random-walk model is a valuable aid in quantifying spray drift, not only because it can simulate the effects on drift of release height, atmospheric stability and the vertical wind profile, but also because it provides an accurate method of incorporating the effects of drop evaporation and partial reflection at the surface. Results from the particular model which has been described here have demonstrated the complexity of the interaction of the various factors which determine drift, underlining the difficulties of extrapolating the results from a limited number of field experiments in order to predict drift over a wide range of initial conditions.

One point of particular interest which has emerged from the calculations is that a large reduction in surface drop deposits caused by partial reflection of drops at the surface will only be observed at relatively short distances from the source: at longer distances increased numbers of drops remain airborne as a consequence of reflection, with most of the additional drops drifting along near the surface, and this tends to compensate for the reduced collection efficiency of the surface.

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RELATIVE CONTAMINATION OF HUMANS AND THE ENVIRONMENT BY SPRAY DRIFT FROM USE OF A TRACTOR-MOUNTED DRIFT SPRAYER (THE ULVAMAST) AND CONVENTIONAL HYDRAULIC EQUIPMENT

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Summary. When the Ulvamast drift sprayer was operated correctly operator exposure to short-distance drift proved to be low but marginally greater than that recorded in operations with a hydraulic sprayer. The drift potential of the Ulvamast spray over longer distances was significantly greater but the possible level of contamination of bystanders and the environment appeared to be low in general. Drift, sprays, pesticides, hazards, contamination, operators, environment.

INTRODUCTION

Controlled droplet size application (CDA) is a familiar term for a means of spraying a uniform cloud of droplets of the correct size to give effective control of a pest with the minimum amount of pesticide and carrying liquid (Matthews, 1979). Spinning disc droplet generators fall into this category but assessments of operator safety have been limited so far to hand-held models (Lloyd, 1979). The development of a tractor-mounted CDA unit, called the Ulvamast (Haigh, 1978), which relied on wind-drift for effective dispersion and impaction of the spray, posed questions therefore about the degree of contamination of operators, bystanders and the environment. Trials clearance was granted by the Pesticides Registration Department, Ministry of Agriculture, Fisheries and Food, and appropriate investigations were undertaken.

Measurements of human exposure to short- and long-distance drift were therefore involved. Drift and human exposure studies demand considerable resources however and the provision of adequate data is often made difficult through problems of weather and timing of operations on farms in the use of one type of spray machine over a short season. As isolated measurements can be difficult to interpret and many factors are involved (Bunyan et al, 1980), procedures were devised to overcome some of these problems and allow the drift potential of the Ulvamast to be compared directly with that of a hydraulic sprayer.

METHODS AND MATERIALS

Description and operation of the Ulvamast (MK2)

The Ulvamast (MK2) is a tractor-mounted spray machine comprising a tank (270 l) from which liquid is pumped to an atomising spray-head mounted on an extendable mast (height 1·25-3·5 m) at the rear of the assembly. The spray is generated (300-900 ml/min) by forcing liquid through small holes in a horizontal spigot around which fifteen serrated plastic discs rotate. The volume median diameter (VMD) of the spray was originally quoted as 60 μm for a rotational speed of 9000 rpm (Haigh, 1978). The discs of the models in use in these trials generally rotated at speeds of 7000-7500 rpm which gave VMD's of approximately 80-90 μm for the emitted sprays measured by sedimentation on to magnesium oxide-coated slides and cellulose acetate films.

The spray is released as the tractor is driven along successive parallel tracks (bouts) at right angles to the wind always working up the field towards the wind. The distance between tracks is required to be 10-12 m for winds 5-8 km/h and 20-24 m for winds 8-16 km/h. The instructions also require that no spray should be applied when the wind-direction lies within 25° of the spray-track or the wind-velocity is <5 km/h or >19 km/h. A sequence of overlapping spray zones is therefore built up as the tractor-sprayer moves upwind.

Control over the volume application rate (usually 2.5 l/ha) is achieved by adjustment of the feed-rate of liquid to the spray-head and of the forward speed of the tractor. A dose rate 10-50% (usually 20%) of that recommended for application of a chemical via conventional nozzles is suggested in the instructions with a warning not to use scheduled pesticides.

Operational use of sprayers

Measurements of exposure to pesticides and drift under commercial conditions were made by analysis of the chemical in use whereas in studies of the relative drift potentials of the Ulvamast and a hydraulic sprayer contrasting spray tracers were added to the respective spray tanks. The two sprayers were then driven simultaneously in a pasture, a short-distance apart, up and down a single spray track positioned at right angles to the wind so that the drift from each sprayer passed over the same drift sampling layout (Fig. 1). The reference hydraulic sprayer had a 12 m boom, 0·6 m above the crop, fitted with hollow-cone "insecticide" nozzles 0·35 m apart. Observed tractor-speeds ranged from 9-11 km/h (hydraulic) and from 7-14 km/h (Ulvamast) which led to variable volume rates of application (Table 1).

Table 1

Operational data

Trial Nos.		Sprayer	Bout width (m)	Spray emission		
Commercial applications	Single track spray			pressure (kPa)	by volume (l/ha)	per track (ml/m)
1	2, 16-20	U	12		2·5	3
12, 13, 14		U	12		5	6
3, 5, 7, 10	9, 15	U	22		2·5	5·5
4, 4A, 6, 8, 11	9	H	10	260	200	200
	15-20	H	12	200	240	270

Note: U = Ulvamast, H = hydraulic sprayer (also in Tables 2-4)

Measurement of human exposure to drift

Fortuitous incidents experienced when opening and pouring from containers of pesticides, whatever type of spray machine is used, lead to very varied levels of contamination of operators. Care was taken therefore to exclude driver/ operators in the study from contamination in mixing operations so that only exposure to spray drift would be measured. For evaluation of respiratory hazards, operators and persons acting as bystanders donned respirators modified to simulate the mechanics of normal breathing (Durham and Wolfe, 1962). Spray droplets impacting on the human figure were collected on absorbent gloves and lightweight disposable coveralls covered with thirty-six felt pads (each 50 cm^2). These items were worn only during spray-periods, the "bystanders" occupying positions (Fig. 1) where passers-by would ordinarily be exposed to spray drift. All tractor-cabs in the trials were ventilated via windows or doors.

Collection of spray drift

Various mechanical devices may be used to sample wind-borne particles but collection of spray drift by impaction on static targets offered advantages of simplicity, ease of operation and low maintenance in the field. Collection of droplets by impaction on narrow cylinders appeared to be promising, the efficiency of collection varying inversely with the diameter of the cylinder (Courshee, 1967). As preliminary trials indicated that drift clouds include droplets chiefly within the 30-100 µm range cylinders of 2 mm diameter were chosen as the primary target because the impaction efficiency appeared to be better than 80% (May and Clifford, 1967).

Satisfactory measurements of drift profiles in aerial spraying operations at ultra-low-volume (ULV) rates had been achieved by suspending 11 m lengths of the primary target vertically at different distances downwind (Lloyd et al, 1981). Similar equipment was therefore used in the present study but for ease of operation lightweight sectional carbon-fibre fishing rods were substituted for the original tubular metal masts for suspension of the sampling lines. Inexpensive polyethylene tubing (diameter 2 mm) was used as the vertical sampling target. Only the larger droplets in a drift cloud tend to settle readily on horizontal surfaces and, for the collection of fall-out of spray, strips of filter paper (Whatman No. 1, 0·05 x 2 m) were mounted on flat boards on the ground at each sampling station (Fig. 1).

Meteorology

Measurements of wind velocity and temperature at 0·75, 2 and 4 m above ground were recorded together with changes in wind direction. For convenience wind velocities at 2 m only are reported here but where a specific effect could be associated with a particular measurement more detail is given in the discussion. Approximate wind velocities at 0·75, 4 and 10 m (the Meteorological Office standard measuring height) may be derived by multiplying the recorded velocities (at 2 m - Tables 2 and 3) by 0·9, 1·1 and 1·2 respectively (Meteorological Office, 1969).

Droplet size measurements

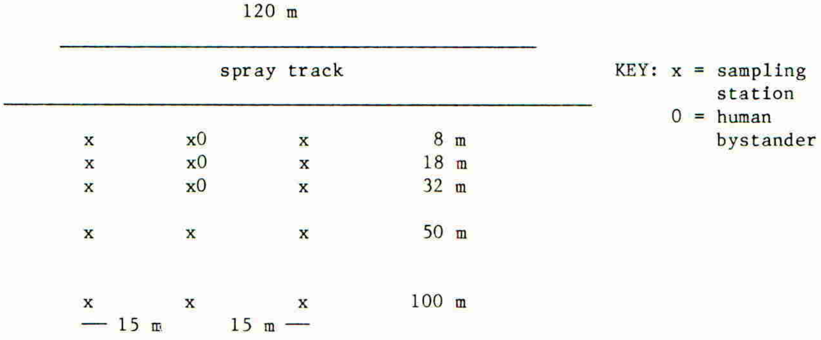
Cellulose acetate-coated strips (Millipore Phoroslides) or magnesium-oxide coated slides were exposed horizontally and vertically to drift clouds on several occasions. For collection and measurement of dyed spray droplets no preparation of the white surface of the cellulose acetate film was required but in circumstances where dye tracers could not be used, chiefly in commercial operations, the surface of the film was pre-dyed by soaking in aqueous nigrosin (0·25%), drained and allowed to dry. Impaction of an aqueous droplet then produced a clear white circular stain against a blue-black background. For droplet size measurement each strip was cleared by soaking in light paraffin oil and then sandwiched between two glass slides. A projection microscope was used to display enlarged images of the droplet stains on the screen of a Zeiss Particle Size Analyser (model TGZ3). A size distribution curve was recorded on the instrument but appropriate corrections had to be made for the ratio of droplet stain diameter to original droplet diameter and the magnification used.

Spray mixtures

For the comparative drift study an aqueous solution of Lissamine Green (0·4%) was sprayed via one spray machine whilst an aqueous solution of Orange G (1%) was sprayed simultaneously from the other. The surface tension of each spray mixture was adjusted to 30-35 dyne/cm. Triadimefon was sprayed predominantly in the commercial operations and applied on one occasion admixed with benomyl and chlormequat (Trial no. 12 - Table 2). Water was the principal diluent but an oil-based additive (10% by volume) was included in several trials (10, 12 and 13) and an oil-based mixture was sprayed on two occasions (1 and 2).

Fig. 1

Diagram of drift sampling layout



Analyses

Proven spectrophotometric and gas liquid chromatographic procedures were used in the analyses of samples. Pre-extraction of sampling media avoided the need for complex clean-up procedures. Aqueous extracts of the spray tracers Lissamine Green and Orange G were measured spectrophotometrically in the presence of each other at 630 nm and 480 nm respectively. All samples were collected immediately after spraying and transferred to stoppered containers, usually with an appropriate solvent, to minimise losses of pesticides by evaporation. The precision of the analytical methods normally fell within 10% measured as a relative standard deviation in the laboratory but as it was not practicable to simulate all possible influences in the field and on-site validation was not practicable an overall precision of 20% was assumed for comparative purposes.

RESULTS AND DISCUSSION

Operator exposure to windborne sprays

Exposure of operators of the Ulvamast and hydraulic sprayers proved to be minimal by inhalation of spray chemicals (all <0·07 mg/h) whatever the conditions and within the range recorded in other trials for a variety of tractor-mounted spray equipment (Lloyd, 1979). The determinable limits varied however with the duration of sampling and analytical factors but when exposure levels by inhalation were expressed as approximate concentrations in air (Table 2) the values were nevertheless lower than Threshold Limit Values (TLV) published for various toxic pesticides (Anon., 1980).

Far higher exposure levels by contact of spray with clothing were observed (Table 2). A relatively high exposure level by contact (74 mg/h) was recorded when the Ulvamast was operated inefficiently and carelessly in a following wind (trial no. 2) which carried the spray into the cab via an open rear window. On another occasion (trial no. 14) the operator collected almost 90% of the recorded total body surface contamination on his hands whilst clearing a blockage in the Ulvamast spray system. Either incident could have occurred in spraying operations with tractor-mounted hydraulic sprayers and may be disregarded when making comparisons between exposure levels. The maximum exposure levels found in operations with the Ulvamast and hydraulic sprayers were therefore of the same order and in no circumstances exceeded 11 mg/h by contact. No clear correlation between exposure levels and wind velocities was apparent but the relatively high values recorded in a light wind (7·6 km/h - trial 9) may have been a result of increased drift through evaporation of droplets in the prevailing high temperatures (24°C average) and bright sunlight.

Table 2

Exposure of tractor driver/operator to short distance drift

Trial No.	Sprayer	Spray liquid	Wind (km/h)	Cab ventilation	Operator exposure to chemical (mg/h):-	
					by inhalation	by contact*
8	H	0·06% triadimefon	3·7	side	<0·012	1·3
2	U	1% simulant in oil	5·4	rear	0·005	74**
7	U	1% triadimefon	5·9	side	<0·003	0·2
10	U	5·8% gamma-HCH	6·6	side	<0·003	0·1
9	U	1% simulant in water	7·6	side	<0·07	11
9	H	1% simulant in water	7·6	side	<0·07	6
11	H	1% gamma-HCH	7·6	side	0·002	0·4
5	U	1% triadimefon	8·0	side	<0·004	3·6
4	H	0·06% triadimefon	8·0	side	<0·012	0·9
6	H	0·06% triadimefon	8·0	side	<0·06	1·0
4A	H	0·06% triadimefon	9·7	side	<0·003	1·2
14	U	1% triadimefon	12·1	side	0·005	86***
3	U	1% triadimefon	12·9	side	<0·004	0·6
1	U	1% simulant in oil	14·0	side	<0·035	<0·4
13	U	1% benomyl	16·2	rear	0·025	4·2
12	U	1% benomyl	21·6	side	0·007	10·4

* calculated for whole body surface ($2m^2$)

** incorrect operation (following wind)

*** operator dealt with blockage - hands contaminated

Assuming a breathing rate of 1 m^3/h by operators, inhalation exposures may be read directly as approximate concentrations in air (mg/m^3).

Relative drift potentials of the Ulvamast and hydraulic sprays

The relative drift potentials of spraying systems may be established by comparative drift measurements or possibly indicated simply by consideration of the droplet size distribution in an emitted spray on the basis that particles smaller than 100 µm are widely recognised to drift readily in the wind. Measurements of droplet size distribution by impaction on suitable targets in these trials confirmed that 100 µm droplets and below were prone to drift and indicated that the drift potentials, based on the proportions of fine droplets (<100 µm) in the Ulvamast spray (VMD approximately 85 µm) and the reference hydraulic spray (VMD approximately 230 µm), were equivalent respectively to approximately 60% and 10% by volume of the emissions. The respective volume outputs were in the ratio of ≮1:50 (Ulvamast:hydraulic) but the corresponding concentrations of pesticide in the sprays were in the ratio of ≯17:1. Equating these factors then the drift potential ratio became <2:1 (Ulvamast:hydraulic), when expressed in chemical terms.

The results of the side-by-side drift study (Table 3) supported the prediction of a higher drift potential for the Ulvamast spray and, on conversion of drift volumes into chemical terms, a fair degree of correlation was observed between the predicted and observed relative drift levels from the two spray machines except in strong winds (>19 km/h), hot conditions (trial no. 9) and when the ratio of pesticide concentrations greatly exceeded 6:1 (Ulvamast: hydraulic). Climatic factors therefore had the major influence on drift in these trials.

Detailed examination of climatic effects is beyond the scope of this paper but of particular interest was the effect of wind on the distribution of airborne spray with height at different distances downwind of the spray track. The volumes of spray collected by the 11 m vertically-orientated targets decreased with distance downwind as expected. Increasingly higher proportions of the total deposits, on each successive target downwind, were found on the upper sections (4-11 m height) at low wind velocities but this trend was reversed at high wind velocities. On the whole, vertical distributions of the airborne fractions of the Ulvamast and hydraulic sprays were similar under comparable conditions. Thus, the drift process appeared essentially to involve diffusion of spray particles in an upward direction, the degree of dilution in air varying directly in proportion to wind velocity and distance from the source.

Drift of spray in commercial operations

Few complete measurements of drift under commercial conditions were possible through problems of timing of spray applications and the lack of access on many farms to downwind zones for placement of drift sampling equipment. Values for drift from the single-track spraying operations (Table 3) were therefore extrapolated to provide an estimate of probable drift levels arising from multiple track applications (Table 4). For the calculation a schematic representation similar to that used to indicate spray deposition from multiple track applications from aircraft (Miller, 1980) was followed and it was assumed that observed variations in drift levels with distance downwind were maintained for each successive swath or bout. Only measurements of particles remaining airborne at different distances downwind were used in the calculations because ground-level deposits on artificial surfaces were less representative of drift and more difficult to relate to capture of spray by different forms of vegetation (Lawson and Uk, 1979). Four downwind drift zones were selected for convenience:- 0-15 m (the headland), 15-30 m, 30-50 m and 70-110 m, the zero point being regarded as the downwind edge of a sprayed area (Table 4). As the first spray track of an Ulvamast normally began 12 or 20 m upwind of the edge of a target area in commercial practice, drift measurements corresponding with this zone, in the single-track spray trial, were therefore omitted from the calculations.

Air turbulence over the headland zone associated with movement of the tractor-sprayers at right angles to the wind and the proximity of trees and hedges on several sites probably accounted for the variable pattern of drift levels recorded in this area (Table 4). Further downwind, drift levels in operations with the Ulvamast tended to follow in proportion to wind velocity but the results as a whole suggested that drift patterns from either machine were likely to be as variable as the distribution of spray on a target crop (Riley and Giles, 1965). In general no significant proportions of the Ulvamast and hydraulic sprays were collected on vertical targets 70-100 m downwind except on one occasion when 4% remained airborne although the wind was light (7·6 km/h). This suggested the presence of fairly stable air which was confirmed by records of only minor variations in temperature and wind velocity at different heights. Relatively high proportions of the Ulvamast spray were also dispersed by strong winds as confirmed in one trial by other workers (Lake et al, 1978) who recorded a significant proportion (2%) of an Ulvamast spray in air 50 m downwind in a wind of 17 km/h.

Relatively low levels of drift recorded under commercial conditions with the Ulvamast on farms, compared with the extrapolated results from single track

Table 3

Relative drift from a single pass of the Ulvamast and a hydraulic sprayer

deposits on vertical and horizontal targets per 1 m pass of sprayer

Trial No.	Sprayer	Wind	Spray (ml)* collected with distance (m) downwind of spray-track				
		(km/h)	7-10m	10-25m	25-40m	40-60m	80-120m
(vertical targets)							
17	U	0·7	0·02	0·03	0·02	0·02	
	H		0·12	0·04	0·03	0·01	
19	U	3·2	0·23	0·14	0·05	0·02	
	H		0·48	0·17	0·09	0·04	
18	U	4·6	0·16	0·12	0·08	0·03	
	H		0·56	0·29	0·14	0·03	
9	U	7·6	2·6	3·0		0·83	0·64
	H		1·7	3·0		1·8	0·66
20	U	10·3	0·61	0·23		0·08	
	H		2·3	1·0		0·37	
16	U	19·4		1·3	1·2	0·26	<0·1
	H			0·94	0·54	0·31	<0·2
15	U	20·2		1·0	0·45	0·29	<0·2
	H			1·8	0·49	0·40	<0·2
(horizontal targets)							
17	U	0·7	0·02	0·02	0·01	0·03	
	H		0·9	0·03	0·01	0·02	
19	U	3·2	0·01	0·03	0·01	<0·01	
	H		0·4	0·02	<0·02	<0·02	
18	U	4·6	0·01	0·03	<0·01	0·01	
	H		0·9	0·05	0·02	<0·01	
9	U	7·6	<0·1	<0·2		<0·3	<0·6
	H		<0·1	<0·3		<0·4	<0·8
20	U	10·3	0·08	0·09		0·02	
	H		0·21	0·30		0·06	
16	U	19·4		0·8	0·3	0·2	<0·1
	H			0·18	0·15	0·04	<0·1
15	U	20·2		0·6	0·1	0·1	<0·1
	H			0·45	0·06	0·12	<0·1

Note: The volume emitted per 1 m pass, see Table 1

* drift volume = the volume of spray carried by the wind through an imaginary frame 11 m (ht) by 1 m situated in the designated zone measured from the centre of the spray-track.
ground deposit = the volume of spray deposited on a strip 1 m wide along the length of the designated zone, measured from the centre of the spray-track;
∴ sample area = 3 m^2 (7-10 m position), 15 m^2 (10-25 m), 15 m^2 (25-40 m), 20 m^2 (40-60 m), 40 m^2 (80-120 m).

measurements, suggested the influence of another factor as no clear association with meteorological variables was apparent. Lawson and Uk (1979) demonstrated that the nature of the surface of a target crop determined its ability to capture spray droplets released from aircraft, fallow fields being less effective than wheat in the removal of droplets transported in the wind; hence through better impaction on the target crop an explanation may be found for the relatively low drift levels in operations on two farms where cereal crops were sprayed in strong winds.

Table 4

Drift from multiple track commercial applications

Wind	Sprayer	No. and width (m) of bouts or swaths	Airborne spray expressed as a fraction % of emission			
			(headland) zone	(downwind from edge of first bout)		
(km/h)			0–15 m	15–30 m	30–50 m	70–110 m
0·7	U	10 x 12	0·5	0·4	0·3	<0·1
	H	10 x 12	0·01	0·002	0·001	<0·001
3·2	U	10 x 12	1·1	0·4	0·3	<0·1
	H	10 x 12	0·02	0·010	0·006	<0·001
4·6	U	10 x 12	1·3	0·7	0·4	<0·1
	H	10 x 12	0·04	0·020	0·012	0·002
6·6	U*	8 x 10	0·9		0·4	
7·6**	U	6 x 20	18·4	10·4	7·7	4·3
	H	10 x 10	0·8	0·64	0·46	0·13
10·3	U	10 x 12	2·6	1·5	1·1	<0·1
	H	10 x 12	0·2	0·12	0·08	0·02
12·1	U*	13 x 24	0·5	0·7		
19·4	U	10 x 12	15·7	7·5	3·5	<0·1
	H	10 x 12	0·06	0·034	0·021	<0·001
20·2	U	6 x 22	4·0	2·6	1·8	<0·1
	H	10 x 12	0·07	0·033	0·017	<0·001

Notes: 0 = downwind edge of first bout (i.e. edge of target area)
* commercial operations - all other results are predicted values extrapolated from single-track measurements
** relatively hot, cloudless conditions

The relative volumes of drift from multiple-track applications (Table 4) nevertheless confirmed the higher drift potential of the Ulvamast spray over the hydraulic spray but allowance must be made for the differential dose rates recommended for CDA and hydraulic sprayers. Thus, for example, a volume rate of 2·5 l/ha and pesticide concentration of 1% (i.e. dose rate = 25 g/ha) in applications via the Ulvamast to an area measuring 100 x 100 m might develop drift levels from 0·075 g up to 1·9 g of pesticide (ref. Table 4), 30–50 m downwind, whereas the corresponding drift values from applications of a hydraulic spray (250 l/ha at 0·1% concentration) might vary from 0·0025 g up to 1·15 g. Beyond this distance spray particles would continue to diffuse and, except under stable (neutral) atmospheric conditions, drift deposits would normally be too low for convenient measurement.

Exposure of bystanders to spray drift

The maximum probable exposure of a bystander to spray drift was expected to be experienced in or close to the headland zone, represented by a strip extending 15 m downwind from the edge of a sprayed area. A human target appeared to be an inefficient collector however of airborne spray particles in these trials and once a spray machine was on its ninth track, at least 90 m upwind, no significant addition to the exposure of bystanders was probable. Exposure levels increased with wind velocity but in winds of >19 km/h the maximum recorded exposure proved to be only 0·02 mg pesticide by inhalation and 10 mg by contact (exposed skin and clothing) in operations with the Ulvamast (pesticide concentration 1% w.v) and 0·002 mg by inhalation and 0·5 mg by contact in operations with the hydraulic sprayer (assumed concentration for comparative purposes 0·1% w.v).

CONCLUSIONS

The studies showed that the operator of an Ulvamast may be exposed to slightly higher amounts of pesticides than the operator of a hydraulic sprayer but the levels would be minimal when the machine is used sensibly. Any precautions advised for the protection of operators of tractor mounted hydraulic sprayers and the Ulvamast should therefore be the same. The higher drift potential of the Ulvamast spray compared with that of a hydraulic spray nevertheless suggests that corrosive or desiccating agents, highly active herbicides such as phenoxyacetates and chemicals of high mammalian toxicity should not be applied by the wind-drift technique without safeguards above those already required for the chemical and prior assessment of the suitability of the site and adjacent areas into which spray particles may drift.

Drift volumes vary directly with wind velocity as might be expected but the risk of high levels of contamination in downwind zones, for example, from the release of an Ulvamast spray into a strong wind, may be reduced through better impaction of spray droplets on the target crop (eg cereals). The degree of air turbulence is a well-known factor in the dispersion of airborne particles and in stable (neutral) atmospheric conditions the intensity of a drift cloud can be at a maximum. Without suitable instruments and skill in their use detection of adverse atmospheric conditions would be difficult on farms but measurements of wind velocities are practicable and indeed required for use of the Ulvamast. With these limitations then, provided "sensitive" chemicals are not applied via the Ulvamast and surface wind velocities are within the manufacturer's operational limits of 5-8 km/h (10-12 m bout) or 8-16 km/h (20-24 m bout) drift problems are likely to be avoided. As an additional precaution in minimising drift from fine aqueous sprays (VMD <100 µm) the addition of non-volatile agents in the ratio of 1:8 by volume would prevent reduction of particle size by evaporation beyond half of the original diameter but droplet size distribution of the emitted spray may be affected (Wodageneh and Matthews, 1981).

The development of mathematical models for the prediction of drift from ground-based spray machines has received far less attention than that given to spray applications from aircraft. Suitable models would clearly provide safety authorities with a useful means of assessment of the drift potential of various systems of application but where observed and predicted concentrations of airborne particles have been compared air concentrations have been underestimated at times by many orders of magnitude (Miller et al, 1980). More extensive and detailed studies appear to be required therefore in operations with ground-based sprayers to be able to predict the movement of airborne spray particles even over a limited range of conditions.

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SESSION 1

THE TENTH BAWDEN LECTURE

Proceedings 1982 British Crop Protection Conference - Weeds

BAWDEN MEMORIAL LECTURE

COMMUNITY AGRICULTURE: ACHIEVEMENTS, AGGRAVATIONS AND AGROCHEMICALS

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Developments in United Kingdom agriculture since accession to the community.

Nine years ago Sir Henry Plumb, then President of the National Farmers' Union of England and Wales, delivered the first Bawden Memorial Lecture. The United Kingdom had been a member of the European Community for only a few months. The Annual Review of Agriculture White Paper for 1973 had reported that "British agriculture as a whole is thriving. ..... The industry is in a condition to develop the opportunities now becoming available and to maintain the impetus of expansion."

But Sir Henry, in that first Bawden Lecture, was less sanguine. He showed distinct signs of anxiety for the future. He warned that farmers and growers would only invest in expansion if they had confidence in the policy framework, and he warned against some of the changes in the Common Agricultural Policy rules which were then being proposed.

I hope that the nine years since accession have reassured the industry. Whatever criticisms there may be of the operation of the CAP - and I shall come to some of them later - the stability, which its overall framework of support has provided, has been striking; and British producers have responded to it.

The outstanding achievement has been a substantial rise in output. The net product of the United Kingdom industry at constant prices was some 16 per cent higher in 1981 than in 1973 and a further rise in output is likely this year. Over the same period there has been an increase in labour productivity of the order of 30% while the capital stock available to the industry has increased by about one-third. The quantity of material inputs has remained broadly stable. At the same time the supply of the most valuable resource of all - agricultural land - has fallen on average by twenty thousand hectares per year because of the need for new housing, factories, reservoirs and so on. There has been a clear and marked improvement in the quantity of output obtained from each unit of input.

All in all, in terms of efficiency and productivity the industry has set an outstanding example to the rest of the British economy.

The substantial rise in total output has improved greatly the United Kingdom's self-sufficiency position. At the beginning of the 1970s our self-sufficiency in indigenous foodstuffs was just over 60 per cent. By 1980 (the most recent year for which figures are available) that figure had risen to 75 per cent, a figure reflecting not only reduced imports but also increased exports. The improvement in our overall self-sufficiency since 1978 alone is worth some £1,000 million a year to our balance of payments.

We must build on this success: there is an urgent need to make the most of our marketing skills to exploit opportunities both at home and overseas, particularly for those commodities for which we have reached or are nearing total self-sufficiency. United Kingdom farmers and growers are in competition here, in the Community market and in the market of third countries, with producers from Member States which have for many years, in contrast to the United Kingdom, adopted an export-oriented policy.

The Government is helping the industry to meet this challenge. On 7 June 1982, Peter Walker announced proposals for the formation of a new marketing body, Food from Britain, to promote and co-ordinate improved marketing of food and agricultural produce at home and abroad. It will provide a unique opportunity to British industry, matching that already existing through central organisations in countries such as France and Germany. It will give a lead to British marketing here and in Europe.

Agrochemicals - achievements and prospects.

The achievements of British agriculture owe a great deal to the crop protection industry, which has made a major contribution to the increases in production and to the improvements in productivity. Your industry has an outstanding reputation for innovation and for ability to adapt quickly to changes in farming and growing practice. The shift in balance from livestock to arable production, highlighted by the intensification in cereal cropping, particularly of winter cereals, and of oil-seed rape has stimulated a demand for new materials and new uses of existing products. Of particular significance is the availability of pesticides to control fungal diseases of cereals which previously could reduce yield seriously.

But your contribution has not been confined to manufacturing alone. Of no less importance is your reputation for scientific excellence. Thus although agrochemicals marketed in this country account for only 5% of the world's total, 20% of the world's research and development in this area, and about 30% of all toxicological testing, is undertaken in United Kingdom laboratories. Your work contributes to agricultural development on a world scale. I do not doubt that this contribution will continue.

However although the expansion of arable farming has undoubtedly given rise to increased use of crop protection products, I believe it would be wrong to assume that the market for your products will necessarily be one of unrestricted growth. There are important counterbalancing factors, particularly of an economic nature. These include the high cost of manufacturing and applying pesticides; the development of increasingly efficient application techniques; improved pest and disease intelligence and forecasting; the cyclical nature of livestock production; and environmental implications.

These economic pressures force the farmer or grower to look very carefully at his imputs, so that any substantial changes in returnes on cereals, for example, could lead to a reduction in the use of pesticides.

I recognise that there would need to be a considerable relative price increase to change the balance between the livestock and cereals sectors. But changes do happen: for example, our entry into the European Community stimulated heavy investment in dairy farming, and more recently improved profits from the sheep regime have led to increased investment here. Comparable trends of this kind, in the future, coupled with reduction in animal losses and wastage through improved fertility, lower mortality rates and better disease control, could shift the balance back towards livestock and thereby influence the growth in demand for your products.

Moreover, quite apart from economic considerations, pesticide usage should be confined to what is essential, in order to minimise the environmental burden of these chemicals. Indeed, the Agricultural Development Advisory Service and the Agricultural Research Service are actively carrying out research towards this end.

Agrochemicals - problems.

Environmental problems pose a particular challenge. Sir Frederick Bawden was concerned about the practical consequences of crop protection measures and his concern was echoed by the Royal Commission on Environmental Pollution which observed that: "the widespread use of pesticides involves some risks for people and for wildlife".

Agrochemicals, by their very nature, do indeed pose potential risks for humans, other living creatures, and the environment. And this is why the registration authorities in this country, as elsewhere, seek to ensure that these products can be used safely. I recognise that the burden imposed upon the manufacturers in meeting these stringent safety requirements - in terms both of human resources and the provision of toxicological and other data - is formidable. But it is right that this should be so, and I know that the manufacturers accept this.

These safetymeasures alone cannot guarantee problem-free use. The efforts of the manufacturers in providing data or of those who have to make the assessment and advise Governments can be dissipated by others who may use agrochemicals carelessly or irresponsibly. Every organisation and individual associated with your industry has a part to play in ensuring that this does not happen.

I illustrate this point by reference to recent experience in the United Kingdom. In 1979, and again in 1980, we had a spate of spray drift incidents which inevitably attracted public interest and caused understandable concern among those directly affected. My Department has mounted special publicity campaigns in each of the last two years. Earlier this year, we sent a reminder direct to each of 40,000 cereal growers; we issued 165,000 copies of a new advisory leaflet; and we prepared special articles for the press and radio. I am glad that on the evidence so far available, there seems to have been a significant reduction in the number of such incidents this year in the light of this campaign. I suggest, however, that greater care on the part of all concerned would have avoided the need for a major campaign of this kind and I hope that it will never need to be repeated on a similar scale.

Episodes such as that I have just described, undoubtedly contribute to another of your problems, which is hostile opinion which you sometimes have to face. We must recognise that people have a genuine concern about the use and possible effects of agrochemicals. That concern needs to be allayed, patiently and thoroughly.

Equally, I recognise that there are others, sometimes operating on an international level, who are quick to exploit the sensational headline but who are less ready to print the facts after the event and when investigations have been completed.

In this climate, your industry must do everything possible to explain the screening processes to which agrochemicals are subjected before they are allowed on the market, and to ensure that they are then used safely. Organisations such as your Council have an important part to play, and so do Governments. Their decisions should be based on the medical and scientific evidence, and not dictated by sectional, political or emotional pressures, however strong these may be.

There is another problem of particular interest to delegates from countries within the Community. This concerns the trading in agrochemicals across national boundaries. Last year, substantial volumes of herbicides claimed to be "identical" to comparable products cleared for safe use here were imported into the United Kingdom. I understand that cross-border trafficking of this kind is not uncommon on the continent, but we had hitherto been shielded from it by the cost of transporting across the Channel.

Those involved in this practice chose not to submit the products for safety clearance. Some of the products bore labels in foreign languages or carried recommendations and precautions that differed from those on products cleared for use in the United Kingdom; and this trading took place at a time when we were receiving reports of the widespread circulation of counterfeit products on the continent.

The Government is very concerned about this development, and we have been considering measures to strengthen the protection given by our safety clearance arrangements and which would be compatible with our Community obligations.

There is need for Community action. It is now six years since the Commission proposed a modest measure, designed to establish a system for the acceptance of plant protection products on a Community-wide basis which would operate in parallel with the national registration systems in Member States. The kind of products that were being marketed across borders withour prior clearance would seemingly be prime candidates for acceptance under the proposed Community measure. But progress on the draft Directive has been bedevilled by a combination of over-cautions parochialism and other considerations extending beyond the plant protection products themselves.

I believe that the time has come to bring this Directive into operation at the earliest opportunity. It would help prevent a recurrence of the kind of problems I have described; it would benefit manufacturers in all Member States by avoiding the need for them to seek registration separately in each of the ten; and clearance for use throughout the Community would, of course, facilitate exports of the products concerned to third countries.

Agricultural trade problems.

So far, I have spoken of the particular problems of agro-chemicals. I have spoken, too, of the contribution which agro-chemicals have made to increasing food production. But this increase in food production has of itself brought yet further challenge.

I refer particularly to our relations with those countries who have traditionally regarded themselves as feeders of the world; and who believe they have suffered from the Community's increasing ability not only to feed itself, but to produce beyond its domestic requirements.

There have been a number of complaints, in recent years, that practices under Common Agricultural Policy are not in compliance with the rules of the post-war free-trading system, as codified in the General Agreement on Tariffs and Trade, or the GATT. This week, in Geneva, a meeting of all the Trade Ministers of the countries concerned in GATT is tackling, amongst other questions, this very issue of how agriculture is regulated in international trade.

We shall have to see what conclusions emerge from that meeting; but at this stage it is worth considering why it is that the European Community has been so at odds with its friends over agriculture.

The majority of the formal complaints which are in progress against the Community under GATT procedures allege that the Community has taken inequitable shares of particular markets for particular agricultural products through the use of export subsidies. Obviously it is not appropriate to comment on the merits of individual cases which are still in progress; but there is a general argument here, and one which will be pursued in Geneva this week, that the CAP's export refund system goes against the spirit of GATT.

This is part of a wider argument which at its most extreme says that agriculture should be subject to exactly the same conditions and rules, when it comes to international trade, as any other industry. That proposition sounds reasonable enough until you come to examine it closely. You can then see, very quickly, that it could never be widely acceptable, and indeed it was not accepted during the last major round of multilateral trade negotiations, the Tokyo Round.

Agriculture has had its own separate treatment in GATT not because Governments have a blind spot about their agriculture industry for some domestic political reason, but because the conditions of agricultural production, with all its variables and imponderables, are such that a certain degree of central intervention, management and support is necessary. Indeed the majority of developed countries devote sizeable levels of their budget to agricultural support. Even in the United States Federal budgetary expenditure on agriculture as a percentage of value added is not far short of the proportion in the Community.

The Common Agricultural Policy does, of course, attract criticism, particularly from other countries trading on world markets. But what these other countries sometimes forget - or choose to forget - is, first, the support they give themselves to their own industries; and, second, the fact that if the CAP in its present form did not exist there would still have to be a European agricultural policy.

The main target of criticism is the high level of price support in the Community relative to world prices and the consequent level of export refunds. Some of this criticism is fair; but if the critics really mean to be fair, they must also acknowledge that the Community is tackling this problem.

What the critics fail to acknowledge is that the Community's presence on world markets is not simply due to export refunds, but to the basic production capacity of European agriculture. And of course, this capacity has been stimulated, as elsewhere in the world, by a host of technical developments, some of which I spoke of earlier.

The basic agricultural potential of Europe has always been there and it should surprise no one that Europe takes its place as a food exporter, as well as continuing to be the major food importer.

The Community's response.

I mentioned a moment ago that the Community is tackling the problem of price levels and exports. I welcome this because the Community has a responsibility towards international markets just as it has towards its own internal market.

In the case of sugar, the revised quota and levy arrangements agreed in 1981 have passed the cost of surplus disposal on to the producers to a very much greater extent than previously: as a result production is likely to become more responsive to the state of the world market. This last year the Community has shown greater awareness of its responsibility along with other sugar exporters for the stability of the world market and has voluntarily held off the market more than 1.6 million tonnes of its exportable surplus.

For milk, cereals and certain other products, guarantee thresholds have been introduced which should mean that if Community production exceeds the agreed threshold, action will be taken to reduce the level of support the following year.

To be effective in the longer term, these efforts will have to be sustained. But at least a start has been made.

Conclusion.

The years since the foundation of this lecture have seen many achievements by agriculture both in the United Kingdom and in Europe. And they have seen achievements in the way in which you have served the industry.

These achievements have brought their problems. These are particularly acute where increase in production have outrun consumption and where, in consequence, international trade has been affected. Undoubtedly, these factors will be of increasing importance in the formulation of agriculture policy.

But let us never forget - there is always one thing much worse than surplus, that is shortage, particularly so far as the consumer is concerned.

AUTHOR INDEX