SESSION 6B

IMPACT OF APPLICATION TECHNIQUES ON THE SAFETY AND EFFICACY OF HERBICIDES

CHAIRMAN	DR E. C. HISLOP
SESSION ORGANISER	MR T. H. ROBINSON

INVITED PAPERS	6B-1 & 6B-2
RESEARCH REPORTS	6B-3 to 6B-7
POSTERS	6B-8 to 6B-10

REDUCING OPERATOR EXPOSURE BY THE IMPROVED DESIGN AND HANDLING OF LIQUID PESTICIDES CONTAINERS.

A J GILBERT

Application Hazards Unit, ADAS Central Science Laboratory,
Hatching Green, Harpenden, Herts, AL5 2BD

ABSTRACT

The shortcomings found in the design and construction of containers traditionally used to supply liquid pesticides are described. This is followed by a description of the ways in which it is possible to improve the user's ability to handle liquid pesticides in a controlled way through more appropriate design and better construction of containers. Reduction in the exposure risk likely to arise to users from handling liquid pesticides in 'wide necked' containers is demonstrated. Improvements in operator protection are anticipated resulting from both provision of better containers and enabling them to be coupled, where possible, to closed transfer systems.

INTRODUCTION.

A risk of exposure to hazardous substances may arise to those who handle and apply pesticides. The degree of risk depends upon the quantity and toxic nature of the pesticide being handled and the practical means or techniques employed to safeguard the user from contamination during handling and application.

Handling concentrated liquid pesticides presents a relatively high potential operator exposure risk, in comparison with other stages in the pesticide application process, because small volumes of very concentrated liquid carry relatively large amounts of active ingredient. This means that contamination of skin or protective clothing with the concentrate can leave a larger deposit of pesticide than would be likely to be picked up while applying the diluted mixture. Furthermore, concentrated liquid pesticides may be formulated in solvents which can increase their tendency for penetration into the surface of protective clothing, giving rise to a greater likelihood of cutaneous contamination from a given level of surface contamination.

Due to the potentially high operator exposure risk arising from opening of liquid pesticides containers and pouring out their contents it is important that container design and construction should be considered carefully to minimise the chances of operator contamination or spillage during handling. In the past, pesticide users frequently found the pouring and handling characteristics of the containers in which pesticides were supplied to them unsatisfactory. Responding to this, the National Farmers Union conducted a survey of their members asking how well pesticides containers were thought to meet acceptable standards (NFU, 1981). The results of this survey highlighted design deficiencies and allowed the compilation of suggestions for making improvements.

CONTAINER DESIGN DEFICIENCIES.

The following features of liquid pesticides containers have been found unsatisfactory by pesticides users.

Container closures.

Lids were criticised for being difficult to remove by hand when wearing protective gloves. If stoppers were fastened too tightly this could cause abrasion of gloves, especially if several small containers were opened in quick succession while filling a large spray tank. The edges of certain stoppers were deliberately milled to aid their being gripped, but this in itself could tear gloves. Sometimes the positioning of the lid would not easily allow the whole of a gloved hand to gain an adequate grip. Difficulty in opening a lid by hand would prompt the operator to use an inappropriate tool (e.g. a screwdriver) to puncture and remove the lid. Damage to the lid so caused would clearly render the container impossible to reseal. The possibility of contaminating the tool was also a cause for concern, along with the less likely but more serious risk of personal injury (accompanied by possible pesticide contamination) arising from accidents occurring during the procedure. In some cases the closure would not provide an effective seal either when new or if re-closure of the part-used container was required.

Secondary seals also brought problems associated with their removal. Where metal was used the possibility arose of sharp edges forming when the seal was torn back. Sharp edges could cut gloves or hands, again with the attendant risk of contamination of the injury by pesticide. Alternatively, soft metalised plastic secondary seals were found difficult to remove without recourse to using tools or even the gloved finger to clear the container opening and allow the product to be poured without interference from the remains of the seal.

Container opening.

The aperture through which liquid pesticides were poured was frequently found to be too small. This would result in an uneven flow of liquid and 'glugging' during pouring, with a resulting increase in the risk of operator exposure and spillage. Similarly, the position of the container opening made pouring difficult especially to start with as liquid could surge as the container was tipped. Badly positioned openings also increased the chances of pesticide contaminating the top and sides of the container. Contaminated containers were a hazard to the user during handling and labels would become obscured as a result of liquid running down the container side. Attempts to solve these pouring problems by means of vented pouring devices sometimes failed if the devices were unable to withstand rough treatment during handling.

Container handles.

Container handles were often too small to be gripped easily by a gloved hand. This meant that either the protective gloves had to be removed or that only one or two fingers could be put through the handle, in each case reducing the level of potential operator safety and convenience. In certain cases the welding of metal container handles could fail, either requiring the container to be manipulated without the benefit of a handle or risking the container dropping to the ground, leading to spillage, contamination and waste.

Container design.

Several general design features of containers were criticised. Physical deterioration could result if the construction material was incompatible with the product inside, or due to corrosion resulting from outdoor storage and weathering. Badly corroded cans would be prone to leakage or rupture if dropped. Container size was found inappropriate, either because too many small cans needed to be emptied to fill one large spray tank or if too large a container had to be carried and lifted in order to decant only a small fraction of its contents to make up one tankful of dilute spray mixture. The operator contamination risk was found to be greatest for containers over 10 litres with a small opening not well positioned for easy pouring. The shape of some containers was unsuitable; being optimal for stacking and palletising of batches, but at the expense of characteristics suited to their easy manipulation and dispensing of the contents. Containers were found which had sharp edges or projections that could tear gloves or injure their user. Many had rims, handles or recesses which trapped the product, either making it difficult to empty the container or providing a contamination hazard by collecting spilled pesticide.

Labels.

Labels were criticised for falling off, fading or becoming easily obscured by spilt product. Reduced legibility or missing labels increased the risk of inadvertent misuse of a product or of inability to follow label instructions on operator protection or safeguarding the environment.

CONSULTATIVE PROCESS AND REMEDIAL ACTION

In response to information highlighting container design and construction deficiencies, which had been provided by users, a consultative process was established in an effort to bring about improvements. Organisations involved included the Ministry of Agriculture, Fisheries and Food, the Health and Safety Executive, the National Farmers Union, representatives from the pesticides manufacturing and supply industries, as well as from industries concerned with the design and manufacturing of the containers themselves.

This consultative process has been sustained and currently takes the form of the Pesticides Label and Container Design Panel (PLCDP). This is one of four expert panels set up under the Food and Environmental Protection Act (FEPA,1985) to advise Ministers (via the Advisory Committee on Pesticides and its Scientific Subcommittee) on technical matters relating to the proper use of pesticides. One of the first topics discussed by the PLCDP has been the design of containers for liquid pesticides. All the criticisms of former ´traditional´ containers have been considered to compile guidance on improving container design. Containers which conform to such design guidance will be better suited to the role they must serve and are expected to lessen the risk of users being contaminated by concentrated pesticides.

The improved generic container has the following design aspects. It will be robust, product-compatible, and provide an effective barrier between its contents and the environment throughout its intended life (at least the shelf life of the pesticide). It will have effective and simple means for closure and reclosure. Lids and other seals will be removable without the operator needing to use excessive force or any tool which would become contaminated by the product (this does not rule out purpose-designed implements not contaminated in use). The container opening will be wide enough to allow easy pouring and, in combination with its position and the overall container shape, will avoid glugging, surging and splashing. Standard opening dimensions are to be adopted to allow coupling with closed transfer systems if available; present expectations are for 45 or 63mm diameter necks with an ASTM thread. Handles are to be large enough to be gripped by the gloved hand and positioned to aid easy pouring. Hollow handles may optionally be used to allow venting from the opening to the air space above the liquid level, or be sealed off from container´s inside space, aiding complete drainage without trapping product. Ideally there will be a calibrated transparency in the side of the container to help the user to see the contents, allowing more controlled pouring and accurate dispensing of small volumes from large containers.

PRACTICAL EXPERIENCE.

Due to the significant operator exposure risk associated with handling concentrated liquid pesticides much study has been done to quantify contamination hazards arising from this process. Contamination and spillage arising from opening of containers and pouring out their contents has been routinely measured by the Application Hazards Unit, of the ADAS Central

Science Laboratory, Harpenden, using a standardised test protocol (Lloyd, 1982). Such data contributes to the risk evaluation that underlies pesticides approvals through the predictive operator exposure model (Martin, 1986). Use of a standardised protocol has allowed comparison of characteristics of various types of container, of different sizes from one to twenty five litres. Results have largely confirmed that the problems (listed above) associated with earlier containers, which made them pour less well or awkward to handle, could give rise to high levels of potential operator exposure. The range of possible design variations coupled with widely differing abilities of operators to pour from containers using ´correct´ techniques resulted in a wide range of distribution of likely exposure levels. Overall the degree of potential spillage and operator exposure was related to the container size. The likely contamination from a five litre container was greater than that from a one litre container but less than that from a ten litre container. Containers of sizes above twenty litres showed an increased tendency to contaminate the operator, probably due to the difficulty in handling heavy items of this size.

Tests on ´innovative´ designs of containers have confirmed that improvements have been made. Of the design factors which are possible to alter, larger neck opening diameter was expected to produce the most significant reduction in operator exposure risk. ´Wide´ necked containers were expected to pour more evenly, to glug less and to be likely to give rise to less operator contamination than conventional ´narrow´ necked ones of the same capacity. This was tested in a study (Gilbert et al. 1988) commissioned by the British Agrochemicals Association at the ADAS Harpenden Laboratory. Examples of modern designs of ´wide´ necked containers (i.e. 45 and 63 mm. neck diameter) from four different volume classes (1, 2, 5 and 10 litres) were compared with a control group which comprised examples of traditional bottles and cans having ´narrow´ necks, typically 38 mm. diameter. The test group of ´wide´ necked containers was selected in order to represent as many as possible of the available design variations such as hollow or divorced handles, vertical or horizontal handles and round or square plan shape. All the containers were tested according to the standardised Application Hazards Unit test protocol. Tables 1 and 2 show how measured operator contamination and spillage were related between the two groups of containers. It should be stressed that the nominal threshold of contamination expected for each container size class serves only to allow comparison between the two groups of containers and does not imply that contamination is acceptable below any given level. The group of volunteer test subjects who poured from these containers included holders of the National Proficiency Test Council foundation module (PA1) certificate of competence in pesticides application. Training in correct pouring technique would have helped to minimise their spillage and consequent contamination hazard from all types of container. This was reflected in the control data (from older style containers) within which the maximum recorded contamination levels were all at the lower end of the previously measured range, given by the column of data from the predictive operator exposure model (Martin, 1986).

TABLE 1. Comparative operator contamination data.
(after Martin, 1986 and Gilbert et al. 1988)

Container capacity (l)	Nominal expected contamination (ml/pouring)	% of pourings below the threshold (BAA Study 1988) 'wide neck'	'control'	(SC8001) all types
1	0.01	90	80	97
2	0.1	100	100	no data
5	0.2	97.5	100	83.5
10	0.5	96.5	100	93

Similarly, data for the contamination arising from the 'wide' necked containers were grouped towards the lower end of the measured range, however, the highest measured contamination levels actually exceeded those previously recorded for 'older' types of container. This finding was thought to be due to some operators pouring too quickly, encouraged by the 'wide' neck bottles ease in handling, leading to carelessness. Spillage data provided a more indicative measure of the improvement brought about by the modern 'wide' necked containers. Fewer pourings from 'wide' necked containers gave rise to any spillage at all, and measured spillage volumes were greatly reduced (except in the one litre volume class) which indicated that the operator had a higher degree of control over pouring.

TABLE 2. Comparative spillage data. (Gilbert et al. 1988)

Container capacity (l)	% of pourings giving rise to spillage 'wide'neck	control	mean volume spilled (ml/pouring) 'wide neck'	'control'
1	30	30	0.035	0.008
2	15	40	0.032	0.045
5	55	100	0.851	8.29
10	87	100	7.26	40.34

Following on from the modern generic design for liquid pesticides containers, individual pesticide manufacturing companies have developed new containers. These incorporate the generic design improvements such as wide necks, large handles and funnelled shapes that facilitate easy pouring, but are also customised to the company's own style.

FUTURE TRENDS

Manufacturing techniques such as co-extrusion of multi-layered plastics and fluorinated barrier layering give scope to more imaginative design options for containers than were available in the past. This means, for example, that 'twin-packs' can be blow-moulded, enabling two separate products (liquid and solid or two liquids) to be supplied together in a single package. This design requires the two products to be poured out simultaneously, so all of the container contents must be used at once. There is a general trend towards 'single dose' packs, which avoid having to measure out small volumes from a large container with consequent lessening of operator exposure risk.

The trend toward 'single dose' packs is encouraging the introduction of water soluble packaging. This had been used only for encasing wettable powders prior to 1989, but this year a major manufacturer introduced a liquid herbicide supplied in a water soluble bag which is itself dispensed from a plastic pot. The water soluble packaging concept represents a truly closed system for transferring concentrated liquid pesticide from its container to the spray tank. Barring accident or inadvertent mis-use, there is no need for the operator to come into contact with the concentrated liquid at all.

The modern improved packaging so far discussed has all been of plastic construction. However, there is the option of using better designed metal containers to avoid having to dispose of large amounts of contaminated plastic. These can share the improvements of larger handles and wider openings, better placed for easy pouring and supplemented by plastic spouts which help to reduce spillage. There are also possibilities of supplying liquid pesticides in bulk to be transferred in closed conditions into the users spray application system.

Control of Substances Hazardous to Health Regulations (COSHH, 1989) will require that, where practicable, engineering controls are installed to reduce the risk of operator contamination by hazardous substances, including pesticides. Closed systems avoid the need for their user to pour out liquid concentrate during preparation for application. Closed transfer systems for use with vehicle mounted arable crop sprayers must be specially designed to connect containers with the sprayer reservoir unless the containers and spray tank are of compatible or standard design. Initial results from operator exposure tests (Frost et al, 1989) with closed transfer systems show that operator contamination frequency and volume are greatly reduced but that spills, if they occur, tend to be of much higher volume than expected from hand poured containers. Closed systems are also becoming available for hand held sprayers. These tend to be specially designed concentrate containers which become the sprayer reservoir, either with or without needing the operator to add diluent to the liquid for spraying.

Safety of sprayer operators is likely to be improved in the future by a decrease in their risk of contamination with pesticides brought about by a combination of better designed containers and equipment for handling pesticides, together with a higher level of training in safe operational procedures.

REFERENCES

Food and Environment Protection Act (1985) Her Majesty's Stationery Office, 49 High Holborn, London WC1V 6HB

Control of Substances Hazardous to Health Regulations (1989) Her Majesty's Stationery Office, 49 High Holborn, London WC1V 6HB

Frost, A.R; Gilbert, A.J; Bell, G.J; Power, J.D. (1989) Measurement of the performance of closed chemical transfer system components. Divisional note DN No. 1507. AFRC Institute of Engineering Research, Silsoe, Bedfordshire, MK45 4HS.

Gilbert, A.J; Bell, G.J; Samuels, S. (1988) Measurement of operator contamination and spillage arising from opening and pouring out the contents form a selected range of liquid pesticide containers. MAFF Contract Report No. C880373 for British Agrochemicals Association, 4 Lincoln Court, Lincoln Road, Peterborough. (In confidence)

Lloyd, G.A. (1982) Operator Protection Group laboratory test for the measurement of spillage on pouring from containers of liquid pesticides. OPRG Report No. EM/6/82. (AHU Standardised test protocol), ADAS Central Science Laboratory, Hatching Green, Harpenden, Herts AL5 2BD.

Martin, A.D. (1986) Estimation of exposure and absorption of pesticides by spray operators. Scientific Subcommittee on Pesticides and British Agrochemicals Association Joint Medical Panel document No SC001 (In confidence).

NFU (1981) Pesticides Container Design. National Farmers Union, Agriculture House, Knightsbridge, London SW18 7NJ

PLCDP (1989) 'Guidelines for Design of Liquid Pesticides Containers' Document No. PLCD 6/5 (draft). Pesticides Label and Container Design Panel, MAFF (Pesticide Safety Division), Ergon House, c/o Nobel House, 17 Smith Square, London SW1P 3JR.

AN EVALUATION OF CHEMICAL APPLICATION SYSTEMS

I. RUTHERFORD

A.D.A.S., Wrest Park, Silsoe, Bedford MK45 4HS

G. J. BELL

A.D.A.S., Harpenden Laboratory, Hatching Green, Harpenden, Herts AL5 2BD

J. B. S. FREER

Bridgets Experimental Husbandry Farm, Martyr Worthy, Winchester, Hants
SO21 1AP

MISS P. J. HERRINGTON

A.F.R.C. Institute of Arable Crops Research, Long Ashton Research Station,
Long Ashton, Bristol BS18 9AF

DR. P. C. H. MILLER

A.F.R.C. Institute of Engineering Research, Wrest Park, Silsoe, Bedford
MK45 4HS

ABSTRACT

A.D.A.S. and A.F.R.C. scientists have collaborated in a Home-Grown Cereals Authority funded series of experiments to evaluate pesticide application systems. The physical characteristics of conventional hydraulic nozzles were compared with new commercially available twin fluid and swirl jet nozzles. Drop size, velocity and spray drift measurements have been compared. Field trials at a number of A.D.A.S. Experimental Husbandry Farms and commercial farms have tested the efficacy of the various spray systems on common weed species. Spray deposits on the weed surfaces were measured. Weed control and crop yield was recorded at all sites. Results for the first two years of this three year trial show insignificant differences between application methods, not only at full but also at reduced dose rates. Spray drift from the twin fluid nozzle was significantly lower than the flat fan hydraulic nozzles at 100 litres/hectare.

INTRODUCTION

During the last 10 years there have been a number of developments in pesticide application equipment which have attracted farmers. There have been claims for increased efficiency, lower application rates, reduced doses and costs. Despite some success, generally in the hands of enthusiastic owner operators, these systems have not made much impact on the market for traditional sprayers fitted with hydraulic nozzles.

Innovative designs continue to appear, and the need to study them is apparent. But in evaluating application systems there is a need to study the fundamental design of the atomisers to consider which factors are affecting their performance. In recent years much more sophisticated instrument systems have become available, and the ability to measure not only drop size but also velocity presents a new opportunity to more fully understand the spray production and deposition processes.

In this series of trials, commercially available application systems have been selected to provide contrasting values for drop size and velocity. By comparing the newer systems with "standard" hydraulic nozzles, the experiment provides comparative data on the physical characteristics of the sprays, their efficacy, spray deposition, and their safety for the operator, bystanders, and the environment.

This paper reports the work carried out during the first two years, 1987 and 1988, of a three year contract.

MATERIALS AND METHODS

The application systems

For many years, the industry "standard" for boom and hydraulic nozzle spraying has been 20 gallons per acre. With metrication and a general trend towards lower volumes, this has become 200 l/ha, and throughout this series of experiments 200 l/ha is the standard with which the other systems are compared.

TABLE 1. Application systems studied

Application system	BCPC spray quality	Application rate, l/ha
Hydraulic 110° fan nozzle F110/1.6/3.0	Medium	200
Hydraulic 110° fan nozzle F110/0.8/3.0	Fine	100
"Airtec"* twin fluid	Nominally fine	100
"Airtec"* twin fluid	Nominally medium	100
WRW "Superjet"+ HC/0.76/2.75	Medium	100
"Crop Tilter"≠ F110/1.6/3.0	Medium	200

*Supplied by Cleanacres Machinery Ltd, Hazleton, Northleach, Cheltenham, Glos GL54 4LZ
+Supplied by Country Workshop Ltd, Unit 1, Swannybrook Developments, Swannybrook Farm, Kingston Bagpuize, Nr Abingdon, Oxon OX13 5NE
≠Supplied by Ciba-Geigy Agrochemicals, Whittlesford, Cambridge CB2 4QT

All the application systems were mounted on a Frazier Agribuggy. The hydraulic and air circuits were arranged such that each spray treatment could be selected independently to spray the 5 m plot on one or other side of the 12 m boom.

Physical measurements

When spraying with water containing 0.1% surfactant, drop size and velocity distributions were measured 350 mm below the nozzles using a laser-based Particle Measuring System size analyser (Lake & Dix, 1985). Mean distributions throughout the sprays produced were obtained by sampling with an X-Y nozzle transporter at a speed of 50 mm/s. Nozzles were set up in the sizing chamber to give the same flow ratesas measured on the spraying machine and a purging air flow was used to minimise the recirculation of very small drops. All measurements were made spraying vertically downwards.

Initial measurements with the "Airtec" nozzle supported earlier suggestions that the spray from this nozzle was structurally different from those formed conventionally. Additional centre-line measurements of size and velocity distributions were made at distances of 450 and 750 mm below the nozzle to verify that individual spray drops contained air and to quantify this effect for the pressure settings used. Spray from this nozzle was also captured on a silicone oil surface so that drops could be photographed through a projecting microscope.

Spray drift

These measurements were made at Silsoe over a grass/stubble surface approximately 150 mm tall except when using the Crop Tilter when a standing wheat crop approximately 750 mm tall was used. The spraying machine was arranged to spray different coloured dye solutions simultaneously through different nozzle types mounted on either side of the boom and with the boom 350 mm above the crop. Relative drift and operator contamination values were determined using protocols developed by the Application Hazards Unit of the A.D.A.S. Harpenden Laboratory (Lloyd & Bell, 1983). Weather conditions during spraying were recorded at 10 second intervals from the following sensors mounted on a 10 m mast: cup anemometers at 0.6, 1.5, 2.8, 5.0 and 10.0 m above ground level; temperature difference sensors between 2.0 and 6.0 m, 2.0 and 1.0 m, and 2.0 and 3.4 m; wind vane at 7.0 m; wet and dry bulb psychrometer at 2.0 m. This data was analysed by computer to give velocity and temperature profiles above the crop and a measure of atmospheric stability (Richardson Number).

Herbicide efficacy

In 1987 two experiments were conducted at High Mowthorpe Experimental Husbandry Farm in North Yorkshire (sites I and II). In 1988 one trial was completed at a site in Wiltshire (site III) and another at Bridgets Experimental Husbandry Farm, Hampshire (site IV).

The trials were laid out in crops of winter wheat, except for the Wiltshire site where a crop of spring wheat was chosen. In each trial the target weeds were broad-leaved species sprayed in the spring with metsulfuron-methyl at 6 g/ha as 30 g/ha and mecoprop at 570 g/l as 3.5 l/ha. One third of these rates was also compared.

The Agribuggy forward speeds were adjusted to apply the desired volumes. The Airtec was operated at 7.9 km/h and 6.5 km/h for the coarse and very coarse sprays. All other treatments were applied at a forward speed of 9 km/h.

Plot size was 5 m x 24 m (sites I and II), 5 m x 30 m (site III), and 5 m x 15 m (site IV). The trial was a complete randomised block with four replicates and two untreated controls per replicate. The spray was made up in 50 l/ha of water to ensure that there was adequate spray for all treatments. The dead volume in the pipes, sump and pump was approximately 10 l. Spraying took place on all occasions in good crop and weather conditions.

Weed assessments were made at least one month after treatment by recovering all above ground weed and measuring total dry weight. Plant counts made at sites III and IV. Assessments were from 20 x 0.1 m^2 quadrats per plot at sites I and II, and 10 x 0.1 m^2 quadrats per plot at sites III and IV.

The yield of grain was measured at each site. A combine harvester cut of at least 34.5 m^2 was taken through the centre of each plot and the yield was adjusted to 85% dry matter.

Crop growth stages at the time of application were: site I GS 13 to 22 on 14 April 1987, site II ranged from GS 14 to 30 on 22 April 1987, site III was GS 30-31 on 12 April 1988 and site IV was GS 30 on 11 May 1988.

Spray deposits

Spray deposition was measured on 2 sites in 1988 on weeds (Viola arvensis) sampled from replicate plots treated with a 1/3 recommended herbicide dose to which was added an emulsifiable concentrate of the fluorescent tracer Helios to give a theoretical dose of 20 g tracer per ha. The actual dose of tracer applied at each site was calculated from the spray volumes applied and the concentration of tracer measured in samples of the diluted spray mixture. Quantitative measurements of tracer deposits on weeds were made after extraction. (Cooke et al, 1986). After measurements were complete, the weeds were dried and weighed and the results are presented as ng tracer per g dry weight for a tracer dose of 1 g per ha.

Qualitative measurements of the percentage of the area of weed leaves covered by spray were obtained by photographing in ultra violet light the ad and abaxial surfaces of leaves from 10 replicate weeds per spray treatment.

RESULTS

Physical measurements

Measured drop sizes and mean velocities are summarised in Table 2. Results from the standard medium hydraulic nozzle (F110/1.6/3.0) and the nozzlesused with the Crop Tilter, which angled the spray rearward by 20°, gave no differences in drop sizes, and mean values are given in Table 2. The BCPC spray qualities given for the "Airtec" nozzle are based directly on the size analyser output and have not been adjusted to account for air inclusions in the drops produced by this nozzle. These air inclusions were clearly visible on the photographs - see Fig. 1. Comparisons of the measured drop size/velocity profiles at 700 mm below the nozzle with those predicted by a computer program (Miller & Hadfield, 1989) based on input conditions measured 400 mm below the nozzle indicated that approximately 30% of drop volume was made up of air inclusions. Larger drops (>450 µm) behaved as though they contained more than 30% by volume of air and there was some evidence that the percentage of air in drops was higher when using the higher air pressure/finer spray quality setting. Data from both the size/velocity profile measurements and the analysis of the photographs showed that drops less than approximately 100 µm in diameter did not have any air inclusions. Further details and results of the work relating to the study of drop size/velocity profiles is being reported elsewhere. (Miller & Tuck, in preparation).

TABLE 2. Summary of drop size, velocity and nozzle operation

Spraying system	VMD µm	% vol <100 µm	Diameter, µm @ 90% vol	@ 10% vol	Mean vertical velocity m/s	BCPC spray category	Pressure kPa	Flow rate l/min
Hydraulic nozzle F110/1.6/3.0	254	2.23	338	164	3.83	Medium	300	1.60
Hydraulic nozzle F110/0.8/3.0	240	2.15	323	163	3.12	Fine	300	0.80
Hydraulic nozzle Delavan WRW Superjet HC/0.76/2.75	269	0.56	364	184	1.16	Medium	275	0.76
Airtec 1.4/3.0	332	0.59	461	213	2.16	Coarse*	300L 140A	0.53
Airtec 0.7/2.0	360	0.34	479	224	1.80	Very coarse*	200L 70A	0.53

L = liquid A = air
*Not adjusted to correct for air inclusions

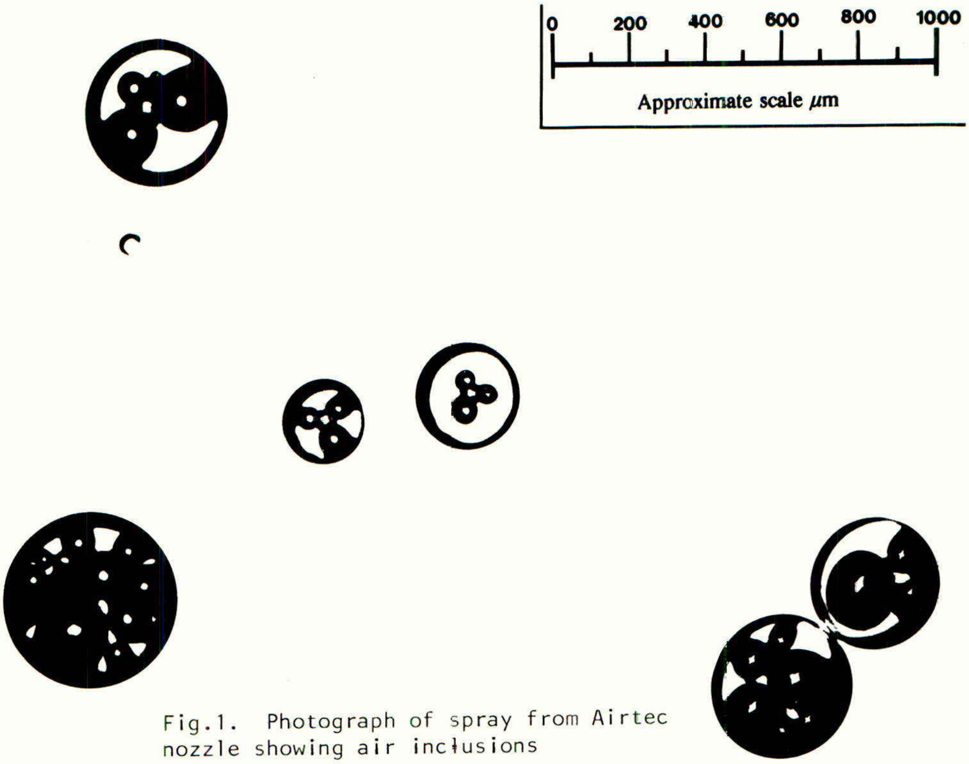
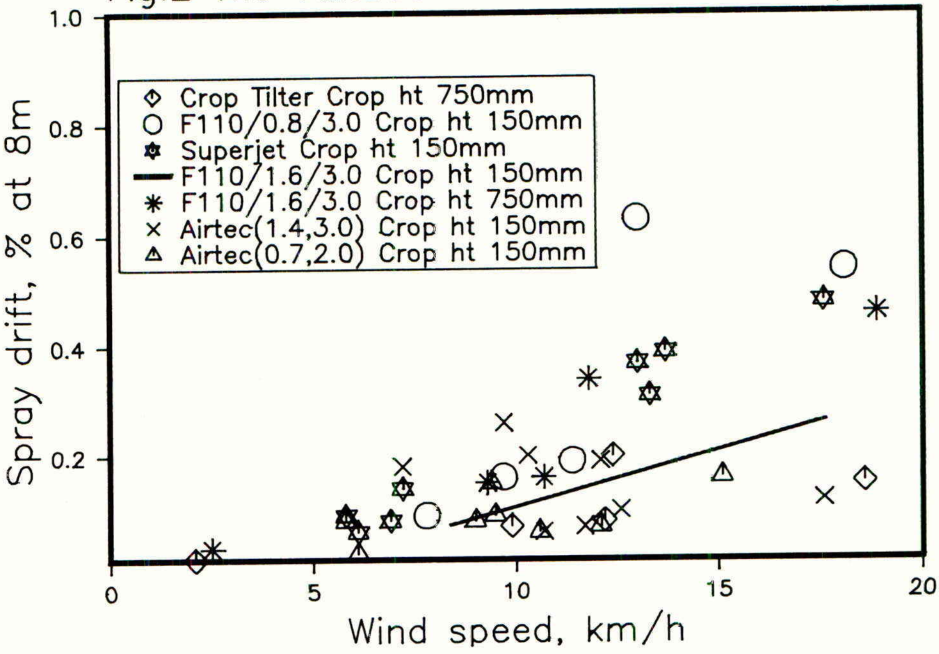


Fig.1. Photograph of spray from Airtec nozzle showing air inclusions

Fig.2 The Variation of Drift with Wind Speed



Spray drift measurement

The variation of drift with wind speed for each of the systems examined is shown in Fig. 2. Drift from the fine hydraulic fan nozzle was approximately twice that from the medium spray quality nozzle. The wide angle low velocity swirl jet produced more drift than the medium fan nozzle even though the results in Table 2 show that the percentage of spray output in drops less than 100 µm is considerably lower for this nozzle. The effects of the lower velocities and shallow trajectory angles probably account for this difference. No major differences in drop velocity or the percentage volume in drops less than 100 µm were found between the two flat fan hydraulic nozzles and further work is required to determine the relationship between these parameters and measured drift volumes for these nozzles. Results from computer simulations (Miller, 1988) have shown that drops less than 100 µm mainly account for spray drift for the release velocities commonly found with hydraulic fan nozzles.

Drift from the "Airtec" nozzle was generally lower than the reference medium hydraulic nozzle for both the pressure settings used in this investigation and this is likely to be a function of the additional entrained air flow from the twin-fluid nozzle together with relatively low percentage of spray volume in drops less than 100 µm in diameter.

The Crop Tilter reduced drift by between a third and a half of that from the standard medium nozzle mainly as a result of operating the boom closer to the top of the crop (Miller, 1988). In one experiment in light winds some spray was apparently lifted out of the crop canopy by the returning deflected stems. This behaviour is likely to be a function of the crop condition and stage of growth and warrants further investigation. Higher drift volumes were recorded when the reference nozzles were operated above a crop 0.75 m tall compared with a crop 0.15 m tall even though the nozzle to crop distance was approximately the same in each case. This result shows the significance of boom height on drift even when operating above a relatively tall crop.

Attempts were made to improve the correlation of measured drift with wind speed by including parameters to account for variations in wind direction and atmospheric stability. Results to date have not given significantly improved correlations by may do so when more data are available.

Herbicide efficacy

Weed dry weight

All herbicide treatments significantly reduced the amount of weed dry matter compared with the untreated ($p = 0.05$). Variations in weed dry weight produced by the different application methods and rates or herbicide were small and non-significant.

TABLE 3. Site I. Weed dry weight
37 days after treatment

Treatment	Full	Third	Mean
Untreated	61.3 g/m^2		
	(SED 11.62)		(SED 8.22)
Hydraulic 200 l/ha Medium	3.5	6.4	4.9
Hydraulic 100 l/ha Fine	4.2	10.5	7.4
Airtec Medium	3.5	13.8	8.7
Airtec Fine	3.7	15.3	9.5
Superjet Medium	5.7	17.5	11.6
	(SED 4.74)		
Mean	4.1	12.7	

SE per plot (33 df) = 16.43 g/m^2 or 95.4% GM

TABLE 4. Site II. Weed dry weight
41 days after treatment

Treatment	Full	Third	Mean
Untreated	123.4 g/m^2		
	(SED 17.09)		(SED 12.08)
Hydraulic 200 l/ha Medium	26.4	46.5	36.5
Hydraulic 100 l/ha Fine	25.3	24.4	24.9
Airtec Medium	35.9	36.9	36.4
Airtec Fine	28.8	47.3	30.0
Superjet Medium	24.8	46.1	35.4
	(SED 4.74)		
Mean	28.2	38.2	

SE per plot (33 df) = 24.17 g/m^2 or 49.2% GM

TABLE 5. Site III. Weed dry weight
43 days after treatment

Treatment	Full	Third	Mean
Untreated	16.1 g/m^2		
	(SED 2.18a 3.69b)		(SED 2.61)
Hydraulic 200 l/ha Medium	2.4	2.2	2.3
Hydraulic 100 l/ha Fine	2.9	4.7	3.8
Airtec Medium	3.5	4.0	3.8
Airtec Fine	2.3	3.6	2.9
Superjet Medium	2.6	2.1	2.4
	(SED 1.65)		
Mean	2.76	3.3	

SE per plot (34 df) = 5.22 g/m^2 or 100% GM

TABLE 6. Site IV. Weed dry weight
58 days after treatment

Treatment	Full	Third	Mean
Untreated	87.6 g/m^2		
	(SED 13.77)		(SED 9.74)
Hydraulic 200 l/ha Medium	19.5	35.8	27.6
Hydraulic 100 l/ha Fine	32.8	34.4	33.6
Airtec Medium	24.1	43.6	33.8
Airtec Fine	38.2	39.3	38.7
Superjet Medium	43.9	49.4	46.7
	(SED 5.62)		
Mean	41.1	48.3	

SE per plot (47 df) = 19.48 g/m^2 or 43.5% GM

Weed assessments

The volumetric assessments at sites I and II showed a considerable weed infestation in untreated plots but good control was obtained by all application methods and both rates of herbicide.

The weed populations at sites III and IV showed a similar pattern. Control of <u>V. arvensis</u> was poor due to the size of the plants at the time of spraying. There were no significant differences resulting from the various methods of application or rates of herbicide.

Yield

The same trend was observed at all sites. There was a significant yield increase from controlling the weeds but no difference between the methods of application or between full recommended rate and 1/3 rate herbicide.

TABLE 7. Mean of all sites. Yield of grain (t/ha at 85% Dry Matter)

Treatment	Full	Third	Mean
Untreated	5.18		
	(SED 0.14a	0.162b)	(SED 0.114)
Hydraulic 200 l/ha Medium	5.82	5.99	5.90
Hydraulic 100 l/ha Fine	5.92	5.84	5.88
Airtec Medium	5.95	5.80	5.87
Airtec Fine	5.87	5.60	5.74
Superjet Medium	5.87	5.76	5.81
	(SED 0.072)		
Mean	5.88	5.80	

SE per plot (131 df) = 0.458 t/ha or 8.0% GM
SED: use (a) to compare untreated vs treated and (b) for comparing treatments.

No significant differences were observed between the various spray systems in terms of weed control or final yield of the crop, despite using 1/3 rate of herbicide in an attempt to magnify any differences.

Under the situations tested (spring broadleaved weed control in good crops of wheat), there was no biological advantage or disadvantage from using any of the spraying systems. However, since the use of a reduced volume of water from 200 l/ha to 100 l/ha had no effect on either yield or weed control, this is of considerable logistic importance and benefit to the farmer. Furthermore, the use of 1/3 rate herbicide gave as good control of weeds as the full rate and did not affect yield.

Spray deposits

Qualitative measurements of the areas covered by fluorescent deposits on the developed negatives were measured with an Optomax image analyser and are summarised in Table 8.

TABLE 8. Overall mean percentage cover on ad- and abaxial surfaces of *V. arvensis* leaves at Bridgets EHF and Bapton Manor Farm, Wyle. (CV's in brackets)

Spray method	Mean % cover			
	Bridgets EHF		Bapton Manor Farm	
	adaxial	abaxial	adaxial	abaxial
Hydraulic	55.2 a	7.6 a	47.0 a	1.8 a
200 l/ha Medium	(36)	(167)	(43)	(197)
Hydraulic	29.6 b	1.0 b	36.5 a	1.3 a
100 l/ha Fine	(46)	(274)	(48)	(100)
Airtec Medium	14.6 cd	1.0 b	31.0 a	1.6 a
	(71)	(194)	(69)	(169)
Airtec Fine	9.0 d	0.5 b	39.3 a	2.2 a
	(64)	(302)	(46)	(141)
Superjet Medium	22.8 bc	0.9 b	39.0 a	1.8 a
	(80)	(152)	(42)	(128)

Treatments in the same column with same superscript are not significantly different at $p = 0.05$%.

The winter wheat crop sprayed at Bridgets EHF was more open and contained larger and older weeds than the spring wheat crop at Bapton Manor Farm, Wyle (mean dry weight per weed respectively 0.065 g and 0.015 g). The quantitative deposit data in Table 9 for Bridgets is unusual (based on previous experience) in that the 200 l/ha spray application method deposited significantly ($p = 0.05$) more tracer on the weeds compared to all other spray methods which were not significantly different. However, at the second spray site, while spray deposits were of a similar size to those at Bridgets EHF, there were no significant differences between treatments.

TABLE 9. Overall mean deposits (ng/g dry weight for 1 g Helios applied/ha) at Bridgets EHF and Bapton Manor Farm, Wyle. (CV's in brackets)

Spray method	Bridgets EHF (mean of 4 blocks)	Bapton Manor Farm (mean of 2 blocks)
Hydraulic 200 l/ha Medium	932 a (26)	830 a (22)
Hydraulic 100 l/ha Fine	563 b (44)	750 a (26)
Airtec Medium	571 b (20)	753 a (14)
Airtec Fine	329 b (31)	779 a (32)
Superjet Medium	443 b (49)	758 a (38)

Treatments in the same column with same superscript are not significantly different at p = 0.05%.

The qualitative deposit data support the quantitative data in that weed foliar cover (hydraulic medium) at Bridgets was significantly different from all other treatments at this site, while at the second site differences were non-significant. The small percentage cover recorded on the adaxial leaf surface for the coarser Airtec spray also coincides with the smallest mean deposit measured at Bridgets EHF. It is also possibly noteworthy that the quantitative deposit data from both sites suggests that the unevenness of spray deposit as measured by the coefficients of variation is greatest for the Superjet compared to all the other flat fan spray applications.

This study suggests that there are no major consistent differences between any of the spray application methods as far as spray deposition measurements are concerned, but that at Bridgets EHF the 200 l/ha treatment might be expected to perform somewhat better than the alternative spray delivery systems.

ACKNOWLEDGEMENTS

This project is the result of the combined efforts of staff from A.D.A.S. and A.F.R.C. stationed at several different sites and experimental husbandry farms. We would like to pay tribute to the excellent levels of co-operation achieved by all concerned. The many problems encountered were overcome by extreme flexibility and goodwill on all sides. Thanks are also due to Mr J. Atterton (Bapton Manor Farm) for his help and co-operation in providing a trial site.

The funding for this work provided by the Home-Grown Cereals Authority is gratefully acknowledged.

REFERENCES

Cooke, B.K.; Hislop, E.C.; Herrington, P.J.; Western, N.M.; Jones, K.G.; Woodley, S.E.; Chapple, A.C. (1986) Physical, chemical and biological appraisal of alternative spray techniques in cereals. Crop Protection, 5, 135-164.

Lake, J.R.; Dix, A.J. (1985) Measurement of droplet size with a PMS optical array probe using an X-Y nozzle transporter. Crop Protection, 4 (4), 464-472.

Lloyd, G.A.; Bell,G.J. (1983) Hydraulic nozzles. Comparative spray drift study. Report of a study carried out in association with the British Agrochemical Association, published by MAFF.

Miller, P.C.H. (1988) Engineering aspects of spray drift control. Aspects of Applied Biology, 17, Pt I, 377-384.

Miller, P.C.H.; Hadfield, D.J. (1989) A simulation model of the spray drift from hydraulic nozzles. J agric Engng Res, 42, 135-147.

Miller, P.C.H.; Tuck, C.R. (In preparation) Droplet size/velocity profiles within the spray produced by different agricultural nozzles.

Sylvester-Bradley, R.; Roebuck, J.E. (1985) Methods for measuring cereal crops. Aspects of Applied Biology, 10, Field trials methods and data handling, 213-239.

EFFECTS OF FORMULATION CHANGES ON THE BIOLOGICAL EFFICACY OF CDA AND HYDRAULIC NOZZLE APPLICATIONS OF TWO HERBICIDES

L.P. MABB, W.K. HICKS

Department of Agricultural Sciences, University of Bristol,
AFRC Institute of Arable Crops Research, Long Ashton Research Station,
Bristol, BS18 9AF, UK

ABSTRACT

The herbicidal activity of commercial formulations of esters of bromoxynil and fluroxypyr against charlock and cleavers, respectively, from controlled drop application (CDA) (40 l/ha) was less than that from a hydraulic nozzle application (200 l/ha) on outdoor-grown plants. In laboratory studies the percentage uptake of commercially formulated ^{14}C-labelled esters of fluroxypyr and bromoxynil was reduced when these were applied at concentrations greater than those used for 200 l/ha hydraulic nozzle applications. Uptake of radiolabelled fluroxypyr and bromoxynil esters could be substantially increased by adding Silwet L-77 and fluroxypyr uptake was enhanced by Synperonic A7. Analysis of dose-response curves confirm that the biological efficacy of CDA applications of fluroxypyr methyl heptyl ester to cleavers could be improved by adding the surfactants L-77 or A7. However, this was not the case for the contact-acting herbicide bromoxynil octanoate on charlock plants.

INTRODUCTION

Herbicide sprays are usually delivered by hydraulic pressure nozzle systems. This technique is biologically effective but entails the use of large liquid volumes and the production of both small and large drops which are poorly retained by the target plant. An alternative method of application is by controlled droplet application (CDA), in which the optimum drop size can be selected for a particular purpose. Theoretically, this technique should facilitate the use of smaller application volumes, decrease drift from small drops and avoid the retention problems resulting from the impaction of large drops on target plants. However, in practice the biological performance of sprays applied with CDA has been variable (Merritt, 1976; Bailey & Smartt, 1976; Lush & Palmer, 1976; Ayres, 1978; Cooke et al., 1985). The composition of commercial pesticide formulations is generally optimised for hydraulic nozzle systems applying volume rates of between ca 100 and 400 l/ha. Consequently, the performance of herbicides has sometimes been impaired when applied at low volume rates and at concomitantly high concentrations (Merritt, 1980).

Previous work at Long Ashton Research Station has compared the performance of bromoxynil and fluroxypyr esters applied at 40 l/ha by CDA systems (Micromax and Tecnoma) with 200 l/ha applications applied with hydraulic nozzles. Under controlled spraying conditions hydraulic nozzle applications gave consistently better weed control than those from CDA. However, no significant difference in the tracer deposition on weeds grown in a cereal crop was found between the two application methods although coverage of the weed surface was significantly less from the lower volume CDA systems.

We have also systematically quantified the spreading characteristics of a range of surfactants from different groups of polyoxyethylene surfactant. Surfactants were tested in the presence and absence of bromoxynil and fluroxypyr esters emulsion and as aqueous solutions on charlock and cleavers. The present work examined the effects on uptake of surfactants that were found to increase the deposit area of 0.2 μl drops of the commercially formulated herbicides. The biological efficacy of these formulation changes were then tested on outdoor-grown plants. A range of herbicide doses were applied in a 40 l/ha volume rate using a horizontal spinning disc and comparisons were made with the conventional 200 l/ha hydraulic nozzle application. Dose-response curve analysis was used to determine quantitatively biological activity (ED_{50}) of the different herbicide surfactant formulations and the methods of application.

MATERIALS AND METHODS

Herbicides

The emulsifiable concentrates of bromoxynil octanoate (Buctril 21) and fluroxypyr methyl heptyl ester (Starane 2) were used in these experiments. These were supplied by Rhone Poulenc and Dow Agrochemicals, respectively, as were the ^{14}C-radiolabelled samples and pure samples. Recommended field dosages of the commercial formulations were 2 (450 g a.i.) and 1 l/ha (200 g a.i.), respectively. For uptake experiments two concentrations of herbicide emulsion were used, equivalent to recommended rates applied as 200 l or 40 l spray volume per hectare.

Surfactants

A range of commercially available polyoxyethylene surfactants from the alkylphenol, linear alcohol, sorbitan ester, amine and organosilicone groups were tested for their effects on the spread of 0.2 μl droplets on cleaver and charlock leaf surfaces. Droplets (0.2 μl) were applied using a Burkard applicator (Silcox & Holloway, 1986) to the youngest fully mature leaf of 5 - 6 week old glasshouse grown plants. Surfactants that were found to increase the deposit areas of droplets on plant surfaces were then tested for their effect on ^{14}C herbicide uptake. Surfactants were incorporated into the commercial herbicide formulations or added to a solution of the a.i. and commercially used organic solvents.

Plant material

Sinapis arvensis (charlock) and *Galium aparine* (cleavers) plants for uptake experiments were grown in 9 cm pots under glasshouse conditions (mean temperature 15°C with supplementary fluorescent lighting). Outdoor-grown plants in pots were used in the track sprayer herbicide performance studies.

Laboratory uptake experiments

Glasshouse plants were pre-conditioned for 5 days in a controlled environment cabinet (14°C/10°C light/dark, 14 h day) prior to use. A precision-microsprayer (Coggins & Baker, 1983) was used to apply ca 100 droplets (250 μm in-flight-diameter) of ^{14}C labelled herbicide formulation to a 3 cm^2 area on the adaxial surface of the youngest fully mature leaves. Plants were returned to the CE cabinet and four replicate samples were harvested at intervals of 4, 24 and 72 h. Radiolabelled herbicide remaining on the plant surface or within the waxes was removed and quantified using the procedure of Baker & Hunt (1986). After wash-off the treated leaf areas and surrounding tissues were combusted using a Harvey OX400 biological oxidiser. The radioactivity in each sample was determined by liquid scintillation counting.

Dose-response experiments on outdoor-grown plants

Commercial formulations of bromoxynil and fluroxypyr esters were applied over a range of doses with or without the addition of surfactants to outdoor-grown pot plants of charlock or cleavers in an enclosed, ventilated, track-spray facility developed at LARS (Hislop, 1989). A boom mounted hydraulic nozzle (04 F110) spray system was used to apply ca 200 l/ha. The hydraulic nozzles were spaced 50 cm apart and the spray delivered 40 cm above the plants. A single horizontal spinning disc (Micromax) 3500 rpm was used to deliver 40 l/ha 60 cm above the plants. After spray treatment, plants were protected from rain and trickle irrigated.

Statistical analysis

Means of radiochemical uptake data are presented with standard errors. Dose-response curves of plant fresh weight data plotted against the logarithm of herbicide dose were used. The equation of the dose-response curve, was that used by Streibig (1988), viz.

$$\log (U) = \log(D-C) / (1+\exp(-2(a+b \log(z)))+C)$$

U = plant weight
z = herbicide dose
D = upper weight limit at zero dose
C = lower weight limit at upper dose
a = horizontal position half-way between the upper and lower limit
b = slope of dose response curve around the ED_{50}

The ED_{50} a/b is defined as the dose that gives 50% of the total effect.

Curves were fitted to the data using the non-linear regression program Maximum Likelihood Program (Ross, 1980). Tests were carried out to detect whether there was non-parallelism but none was detected. Curves were refitted with a common slope and the ED_{50} and corresponding SED values obtained.

RESULTS

Uptake experiments

The spread of 0.2 μl drops of commercially formulated fluroxypyr methyl heptyl ester on cleavers and bromoxynil octanoate on charlock was measured. At recommended application rates of 1 and 2 l/200 l the deposit areas of 0.2 μl droplets were 1.01 (± 0.03) and 1.25 (± 0.02) mm^2, respectively. Deposit areas were increased on both charlock and cleavers leaf surfaces by increasing formulation concentration, or by adding low ethoxylate chain length surfactants or organosilicone surfactants. In the case of charlock increasing the formulation concentration to 2 l/40 l (a typical CDA application) increased the deposit area of 0.2 μl drops to 1.52 mm^2 (± 0.05). The addition of Synperonic A7 (0.5%) or Silwet L-77 (1%) to the recommended bromoxynil formulation concentration (2 l/200 l) increased deposit areas to 1.55 (0.2) and 2.43 mm^2 (0.07), respectively.

Uptake data for ^{14}C-labelled emulsions of the commercial formulations of bromoxynil octanoate and fluroxypyr methyl heptyl ester applied at two volume rates are presented in Table 1. The percentage uptake of radiolabel by both weeds was lower for the higher concentrations of herbicide used, although only the bromoxynil ester was increased significantly.

TABLE 1. Uptake (% applied dose (± SE), n = 4) of commercial formulations containing ^{14}C-bromoxynil and fluroxypyr esters in the presence and absence of added surfactants.

Herbicide/surfactant	Uptake (%) after 72 h Volume rate 200 l/ha	 40 l/ha
Charlock		
Bromoxynil*	40 (2.3)	15.2(0.9)
Bromoxynil + 1% L-77	97.9(0.3)	38.9(0.5)
Bromoxynil + 0.5% A7	54.4(1.0)	19.1(0.8)
Cleavers		
Fluroxypyr**	5.4(0.7)	4.3(0.8)
Fluroxypyr + 1% L-77	35.3(1.7)	9.8(1.1)
Fluroxypyr + 0.5% A7	53.8(33.2)	6.2(0.9)

* Bromoxynil 450g a.i./ha.
** Fluroxypyr 200g a.i./ha.

Addition of 1% Silwet L-77 to the final herbicide volume significantly increased uptake of the bromoxynil and fluroxypyr esters into their respective susceptible weeds. An oil-in-water emulsion prepared from bromoxynil octanoate, 1% L-77 and the organic solvent used in the commercial formulation also gave greater uptake than the commercial formulation containing the equivalent amount of the active chemical. The linear alcohol ethoxylate surfactant, Synperonic A7 (ethoxylate chain length of ca 7) added at 0.5% also increased uptake of ^{14}C-fluroxypyr ester but only from formulations of low a.i. concentration (ca 200g a.i./200l).

Dose-response studies

Herbicidal performance was assessed after CDA and hydraulic applications of the commercial herbicide formulations and of the herbicide/surfactant formulations found to improve radiolabelled herbicide uptake (Table 1). Analysis of the fluroxypyr ester dose-response with and without the surfactants, A7 and L-77, was done on plants sprayed at 40 l/ha using a spinning disc. Conventional 200 l/ha hydraulic nozzle applications of the commercial formulation were also applied for comparison. The biological efficacy (measured as reduction in fresh weight) of the formulation changes was assessed by comparing the slope and ED_{50} parameters of the dose-response curves.

The fresh weight data show heterogeneity of variance and a log transformation of the means was necessary for each dose level for each treatment to allow statistical analysis. Logistic dose-response curves were fitted to the means for each treatment separately and the ED_{50} values obtained. The fitting process assumed that all the curves for both species herbicide combinations had the same zero dose value and took into account the log transformation needed by the data. The slope of the curves around the ED_{50} values did not differ significantly between bromoxynil ester treatments or for those of the fluroxypyr ester treatments. This shows that the change in response for a given increment in dose is similar for all treatments using the same herbicide and weed species.

The ED_{50} values for the bromoxynil and fluroxypyr ester treatments are summarised in Tables 2 and 3. The ED_{50} for the commercial formulation of bromoxynil octanoate applied using hydraulic nozzles was smaller than that of the spinning disc application of the same commercial formulation. Adding L-77 (1%) to the commercially formulated bromoxynil ester or to the emulsion prepared in the laboratory did not alter the ED_{50} values obtained for a spinning disc application.

The ED_{50} value obtained for a hydraulic application of the commercial fluroxypyr formulation was smaller than that for the eqivalent spinning disc application. However, the addition of L-77 (1%) to the formulation decreased the ED_{50} for the spinning disc application to below that observed for the hydraulic application. The addition of A7 (0.5%) also reduced the ED_{50} value for the spinning disc application but to a value similar to that obtained for the hydraulic application.

TABLE 2. ED_{50} values (± ln SED) calculated from the fitted logistic dose-response curves for bromoxynil octanoate applied to charlock at two different volume rates and in the presence of added L-77.

Formulation	Volume rate (l/ha)	L-77 Concentration (% wt/V)	ED_{50} g a.i./ha
Commercial	200	0	9.25 (1.1)
	40	0	23.9 (0.5)
	40	1%	33.2 (0.5)
a.i. + commercial solvent	40	1%	31.4 (0.7)

TABLE 3. ED_{50} values (± ln SED) calculated from the fitted logistic dose response curves for commercially formulated fluroxypyr ester applied to cleavers at two different volume rates and in the presence of additional surfactants.

Volume rate (l/ha)	Additional surfactant	ED_{50} g a.i./ha (conc.)
200	-	5.2 (0.6)
40	-	9.0 (0.3)
40	L-77 (1%)	2.6 (0.3)
40	A7 (0.5%)	4.7 (0.3)

DISCUSSION

Uptake of radiolabel (as percentage of dose applied) from ^{14}C-labelled fluroxypyr and bromoxynil esters added to commercial formulations was reduced when the concentration of herbicides and associated formulants exceeded the rates recommended for a 200 l/ha application (200 and 450g a.i./ha, respectively). Poor herbicide uptake from low volume CDA applications therefore probably accounts for the reduced biological performance associated with CDA of these two herbicides. Improved uptake of ^{14}C bromoxynil octanoate by charlock was achieved by adding 1% L-77 to both the commercial formulation and the emulsion prepared from the a.i. and commercial solvent. Uptake of ^{14}C-fluroxypyr by cleavers was also improved by adding L-77 (1%) and, at low active ingredient concentrations, by A7 (0.5%).

In the absence of additional surfactants spinning disc application of the commercially formulated fluroxypyr ester gave a larger ED_{50} value than the higher volume hydraulic application of the same formulation. The addition of L-77 (1%) to the fluroxypyr formulation reduced the ED_{50} below that observed for the hydraulic application. A similar result was also found for the spinning disc application of commercially formulated fluroxypyr with the addition of A7 (0.5%). In the latter case, the ED_{50} was reduced to that given by the hydraulic application of the commercial formulation. Improving the uptake of systemic herbicides such as fluroxypyr with adjuvants may thus provide a means of improving their biological performance by CDA.

No significant improvement in the biological activity of spinning disc applications of bromoxynil octanoate to outdoor-grown plants was achieved by adding L-77 although improved uptake occurred in our laboratory studies. The lack of enhancement is consistent with the contact mode of action of the herbicide. In this instance adequate uptake of herbicide may have already been obtained from the commercial formulation such that any improvement in uptake does not lead to enhanced biological activity. Alternatively, localised overdosing may have occurred, as described by Merritt (1980) for the reduced biological performance of difenzoquat applied at high concentrations to wild oats.

Reformulation, or the addition of adjuvants to commercial formulations, may be necessary to provide adequate biological efficiency of systemic pesticides applied through low volume spraying systems. However, for contact herbicides reformulation to increase cover of the plant surface without necessarily enhancing uptake may be desirable for optimal performance in the field.

ACKNOWLEDGEMENTS

We are grateful for the financial support of MAFF. We also thank Drs E.C Hislop and E.A. Baker for their helpful advice and discussion, Dr P. Brain for his assistance with the statistical analysis, Mr R. Hughes and his staff for raising plants and maintenance of CE facilities and Mrs J. Hynam for typing the manuscript.

REFERENCES

Ayres, P. (1978) The influence of application method on the control of blackgrass (Alopecurous myosuroides Huds.) in winter wheat by post-emergence applications of a range of herbicides. British Crop Protection Conference - Weeds, 2, 687-693.

Bailey, R.J.; Smartt, A. (1976) The results of a controlled drop application technique for herbicides in cereals. British Crop Protection Conference - Weeds, 2, 383-389.

Baker, E.A.; Hunt, G.M. (1986) Ethylene production: a direct measurement of biological response to foliar applied chemicals. In: Biochemical and physiological techniques in herbicide research Aspects of Applied Biology, 11, 169-179.

Coggins, S.; Baker, E.A. (1983) Microsprayer for the laboratory application of pesticides. Annals of Applied Biology **102**, 149-154.

Cooke, B.K.; Herrington, P.J.; Jones, K.G.; Western, N.M.; Woodley, S.E.; Chapple, A.C.; Hislop, E.C. (1985) A comparison of alternative spray techniques in cereals. British Crop Protection Conference Monogram No. 28 Symposium on Application and Biology, 299-309.

Hislop, E.C. (1989) Crop spraying under controlled conditions. *Aspects of Applied Biology Comparing laboratory and field pesticide performance* **21**, 119-120.

Lush, G.B.; Palmer, R.A. (1976) Field trials comparing the biological effectiveness of CDA with conventional hydraulic pressure spraying. *British Crop Protection Conference - Weeds* 391-397.

Merritt, C.R. (1976) The interaction of surfactant type and concentration with controlled drop application of MCPA and difenzoquat. *British Crop Protection Conference - Weeds*, 413-417.

Merritt, C.R. (1980) The influence of application variables on the biological performance of foliage applied herbicides. *Symposium on Spraying Systems for the 1980s* (Ed. Walker, J.O.), British Crop Protection Monograph No. 24, Thornton Heath: BCPC Publications, 35-43.

Ross, G.J.S. (1980) Maximum Likelihood Program. Rothamsted Experimental Station, Harpenden.

Silcox, D.; Holloway, P.J. (1986) Techniques suitable for the determination of foliar uptake, movement and metabolism of non-ionic surfactants. *Aspects of Applied Biology Biochemical and physiological techniques in herbicide research* **11**, 1-12.

Streibig, J.C. (1988) Herbicide bioassay. *Weed Research* **28**, 479-484.

EVALUATION OF OPERATOR EXPOSURE AND SPRAY DISPLACEMENT WITH HAND-OPERATED HERBICIDE APPLICATION SYSTEMS.

C.R. MERRITT

Cranfield Institute of Technology, Cranfield, Bedford, MK43
0AL.

ABSTRACT

Techniques and trials designs are described for the determination of spray operator exposure and short distance spray displacement during the application of herbicides using hand-operated equipment.

Examples of results are given for trials carried out during 1988 and 1989, showing that two novel application systems can reduce the amounts of operator contamination and spray displacement compared with a conventional lever-operated sprayer.

INTRODUCTION

With increasing demands for safer and more efficient methods of pesticide use, there have been many studies of the potential exposure of spray operators to pesticide contamination, and of the potential for environmental and non-target contamination.

One major, well-quoted study was carried out in 1983 by the by the British Agrochemicals Association, in cooperation with the MAFF Operator Protection Group (now the Application Hazards Unit) and the Robens Institute, Surrey University (Abbot *et al.*, 1987). This work revealed that operator contamination was greater for hand-operated spraying than for applications by tractor-powered boom sprayers. The study also showed that the mixing and loading process can lead to particularly high risks of contamination.

Hand-operated sprayers are widely used for the application of herbicides for Industrial, residential and amenity weed control, as well as for small scale applications in agriculture and horticulture. In such operations it is necessary to minimise the displacement of spray material from the target zone, since often there may be unexpected human bystanders or sensitive plant material in the immediate vicinity.

Recently, several new hand-operated application systems heve been developed which employ containers of pre-mixed herbicides in order to relieve the operator of some tasks, and potential risks of contamination, arising from the handling of formulations and the preparation of the sprayers for use. However, any new systems of application must be evaluated for their potential to give rise to personal and environmental contamination.

This paper describes a series of trials carried out during 1988 and 1989 to evaluate two such novel systems for herbicide application, in terms of the potential operator exposure, and the drift or displacement of spray liquid, during their use. The systems evaluated were the 'Nomix' rotary atomiser system (Nomix Manufacturing Co. Ltd.) and the 'Transformer' sprayer (Ciba-Geigy Ltd.) which uses hydraulic nozzles.

Particular emphasis is given in this paper to the assessment techniques and trials methodology, which have been developed in order to provide an objective approach to the comparison of spraying systems against a standard conventional system. Examples of results are included to illustrate the typical outcome and interpretation of the trials.

MATERIALS AND METHODS

General approach and trials design

Spraying operations were carried out in field trials on an open, flat site at Cranfield Airfield, Bedfordshire, over disused concrete runway in most cases, or short grass in one trial. Six trials were carried out between 21 June 1988 and 25 April 1989.

Each trial consisted of a number of replicate operations (usually four), for a number of different application systems (also usually four). The spray operations in any one trial were arranged over a single day, so that all treatments of replicate 1 were sprayed first, then all of replicate 2, and so on. In this way, a blocked experimental design was achieved, minimising bias due to changing meteorological conditions. Wind speed and temperature were monitored throughout the trials.

Each replicate spray operation consisted of a number of passes (usually 10, 5 in each direction) along a 25 metre track. The track was laid out either approximately perpendicular or parallel to the wind direction. When spraying perpendicular to the wind direction, spray displacement was measured using spray collectors at various heights and distances along a line perpendicular to the spray track at its centre.

In most trials a standard, conventional spray treatment was included, namely a Cooper-Pegler CP15 sprayer fitted with a 'Polyjet' Yellow spray nozzle, and calibrated to deliver approximately 200 litres/ha. Trials 1 - 5 included the 'Nomix' controlled drop applicator, fitted with either the small, square atomiser or the toothed, circular atomiser supplied with the sprayer. Various actual and simulated formulations were used with the 'Nomix' sprayer in the various trials, and different rotational speeds, flow rates and forward speeds were compared. Trial 6 included the Ciba-Geigy 'Transformer' sprayer, with an intended volume rate of 50 litres/ha. This sprayer was used with a formulation of terbuthylazine and atrazine.

Wind speeds of around 2 m/s at nozzle height were intended for the trials, this being at the upper margin of speeds recommended for herbicide spraying under current UK pesticide legislation. In most cases speeds somewhat higher than this were actually recorded.

Operator contamination and spray displacement were determined using sodium fluorescein as a tracer, dissolved in the spray liquid. After spraying, the tracer was recovered from items of protective clothing worn by the operator, and from the spray drift collectors. In most cases actual herbicide formulations were used, although in the trial over grass, simulated formulations were used, and in most trials the standard, conventional spray treatment used 0.1% v/v surfactant solution ('Agral', a nonyl phenol ethoxylate). Liquid physical characteristics (surface tension, viscosity and density) were measured to ensure that the addition of fluorescein did not significantly modify these properties. Droplet spectrum data were also determined, using a Particle Measuring Systems (PMS) laser probe, both with and without the addition of fluorescein to the formulations.

Assessment of operator contamination

Operator contamination was measured by destructive analysis of protective clothing worn by the sprayer operator, based on the methods used by the MAFF Application Hazards Unit (A.J. Gilbert, personal communication). The following items were used:

Protective suits

One-piece disposable 'coveralls' of 100% polypropylene material (Kimberly-Clark, 'Kimguard'), medium size. These were marked in advance using an indelible marker pen, into various sections, namely head, body (back), body (front), arms, thighs and lower legs (in all cases left and right separately). The sections were cut immediately after spraying and placed in polythene bags for subsequent extraction of fluorescein in the laboratory.

Gloves

Vinyl disposable gloves (Kimberly-Clark, 'Kimguard') medium size.

Respirators

Exchangeble filter respirators (North, 'Droop Snoot') were fitted with modified filter canisters containing 20 layers of fine nylon gauze, similar to the method of Durham and Wolfe (1962).

Personal samplers

For an additional estimate of respirable contamination, personal samplers (Casella AFC 123), were used, with an aspiration rate of 2 litres per min through glass fibre filter discs (Whatman GF/A 37 mm diam.).

Rubber wellington boots were worn during spraying but were not extracted. Protective coveralls were worn outside the boots, so that the lower leg sections provided a measure of contamination on the boots above ankle level.

Assessment of spray displacement

Spray displaced to the downwind side of the spray line was assessed by placing two replicate collectors at distances of 2 and 8 metres downwind and at heights of 0.25, 0.75 and 1.5 metres above the ground. The collectors used were perforated plastic cylinders (hair curlers, 38 mm diam. by 60 mm length). These have been shown to have a very high collection efficiency for drifting spray (Bury, 1987).

RESULTS

Validation of methodology.

Experiments to validate the methodology gave mean recoveries of fluorescein from the disposable coveralls of 99.1% with a range of 89 to 104% (coefficient of variation 3.9%). There were no differences between fluorescein recoveries from suits washed immediately compared with others which were left for 48 hours in the dark before washing. Similarly, fluorescein solutions stored for 48 hours showed similar readings to identical samples read immediately.

In an experiment to determine the risk of fading of fluorescein deposits, standard aliquots (10µl) of fluorescein solution were placed on samples of the protective coverall material and placed horizontally outdoors in full August sunlight, between 11.00 and 16.00. Samples removed periodically and extracted showed that fading was initially rapid, reaching about 10% loss after 10 mins. fading appeared to level of at around 40% loss after 2 hours. For the operator exposure trials, spraying was carried out in cloudy conditions wherever possible to avoid this problem. Furthermore, a single replicate could be sprayed and the coveralls removed to a shaded vehicle within about 5 minutes.

Trials results.

As an illustration of the results obtained in the field trials, data for the standard spraying system have been extracted from 5 trials, and a total of 14 replicate spray operations.

The data for spray displacement (Table 1) showed greatest levels at the lowest and closest sampling point, as would be expected. Replicate collectors in any spray run showed very close agreement, and even between replicate runs and trials the variability was low. This is shown by the surprisingly low coefficient of variation of the collectors at 2 metres distance and 0.25 metres height, bearing in mind that these data come from spray runs on different days, with varying wind conditions. At other height and distances, the variation increased due to the very low deposits recorded.

Table 1. Summary of spray displacement data for 14 replicates taken from 5 trials using the standard system (CP15 sprayer). Data are volumes of spray liquid recorded on collectors expressed as µl per litre applied. Mean wind speeds varied from 2.3-4.8 m/s at 2m height.

Distance (m)	2	2	8	8	8
Height (m)	0.25	0.75	0.25	0.75	1.5
MEAN	11.23	0.48	1.03	0.76	0.26
Minimum	2.11	0.01	0.13	0.11	0.04
Maximum	20.70	1.45	2.37	2.20	0.70
S.D.	4.980	0.404	0.729	0.529	0.223
CV(%)	44.3	83.5	70.6	77.6	85.3

S.D. = Standard deviation; C.V. = Coefficient of variation.

Data for contamination of protective suits (Table 2) identified the lower leg sections as having by far the greatest deposits. Next in order to these were the deposits on the thigh and body sections, which overall were approximately 100 times lower. As an indication of the practical significance of the levels of contamination, the time required to lead to a contamination of 1 gram a.i. is showm in Table 2. These were calculated assuming a dose of 1 kg/ha, volume rate of 200 litres/ha and a flow rate of 0.6 litres/min., which was typical of the sprayer. Only the lower leg levels would be regarded as significant.

Levels of contamination recorded on gloves were generally small compared to the levels on the legs and thighs, and contamination of respirator and personal sampler filters were extremely low.

To indicate the results obtained with the novel spraying systems, Table 3 shows data extracted from three trials. Both the 'Nomix' and 'Transformer' sprayers gave reductions in the levels of operator contamination and short distance spray displacement.

The 'Nomix' sprayers gave particularly large reductions in spray deposits recorded at 0.25 metres height and 2 metres distance from the spray line (in the order of 3% of the levels recorded with the conventional sprayer).

All three systems showed large reductions in the levels of contamination of the protective suits, particularly the lower leg sections, where greatest contamination occured. Comparison between trials in Table 3 should be avoided, since wind speeds varied significantly, being much lower in trial 5 than trials 3 and 4.

Table 2. Summary of data on contamination of protective suits for 14 replicates taken from 5 trials using the standard system (CP15 sprayer). Data are volumes of spray liquid recorded on suit sections expressed as μl per litre applied. Wind speeds as in table 1.

Suit Section[a]	MEAN	Min.	Max.	C.V.(%)	% of suit Total	Hours for 1g exposure[b]
Head	0.76	0.0	4.2	161.7	0.3	7,275.8
Body, Fr.	1.93	0.0	12.3	168.4	0.8	2,880.7
Body, Ba.	2.76	0.0	19.5	182.7	1.2	2,009.8
Arm, L	0.68	0.0	3.5	136.5	0.2	8,135.8
Arm, R	0.90	0.0	7.1	208.0	0.4	6,197.4
Thigh, L	2.86	0.0	22.1	201.8	1.4	1,942.0
Thigh, R	1.54	0.0	11.5	200.8	0.7	3,619.9
Leg, L	198.11	0.0	745.0	113.8	46.5	28.0
Leg, R	210.47	0.0	841.6	117.4	52.5	13.2

[a] Fr = front; Ba = back; L = left; R = right; Leg = leg below the knee.
[b] Calculated assuming a dose of 1 kg/ha, a volume rate of 200 litres/ha, and a flow rate of 0.6 litres/min.

DISCUSSION

The methods described in this paper have been found robust and versatile for field use, with the one limitation of avoiding their use on days of bright sunlight. Consistency of the data, particularly the spray displacment data, indicate the reliability of the techniques.

The experimental design, with replication of defined spraying operations, allows the blocking of treatments over a day, which helps alleviate the inevitable uncontrolled variability due to changing meteorological conditions during field spraying operations.

The trials were intended to simulate herbicide applications of the kind used for maintenance weed control in industrial and amenity situations. There would be some limitations to extrapolating from this situation to different circumstances, such as spraying dense or tall vegetation, where transfer of spray from foliage to operator would be a major factor. Also, the possible effects of turbulent air movements when spraying near building are missing from the trials as described.

Under the conditions of the trials, the data convincingly demonstrate the potential of two novel spraying systems to reduce both the contamination of the operator, and the amounts of spray displaced from the target, in comparison with a

Table 3. Spray displacement and operator contamination data for novel spraying systems in comparison with the standard system (mean μl spray liquid per litre applied). Only replicates sprayed perpendicular to the wind are included.

		Trial 3		Trial 4		Trial 6	
No. Replicates		5		2		2	
Sprayer [a]		NX,SE	CP	NX,SQ	CP	TRANS	CP
<u>Collectors</u>							
Dist. (m)	Ht. (m)						
2	0.25	0.3	11.6	0.4	11.5	3.2	14.2
2	0.75	0.2	0.5	0.3	0.1	0.1	0.7
8	0.25	0.3	1.2	0.4	1.9	0.1	1.2
8	0.75	0.2	1.0	0.4	1.0	0.1	0.5
8	1.5	0.1	0.3	0.3	0.2	0.1	0.2
<u>Suits</u>							
Head		0.1	0.8	0.1	0.2	0.2	2.4
Body, Fr.		0.3	1.7	3.5	0.8	0.1	0.0
Body, Ba		0.6	1.5	4.6	1.4	0.0	9.7
Arm, L		0.1	0.6	0.3	0.5	0.5	1.8
Arm, R		0.5	0.2	0.0	0.2	0.5	5.0
Thigh, L		0.6	0.5	0.4	4.1	0.0	11.1
Thigh, R		0.1	0.1	1.0	3.6	0.0	5.8
Leg, L		97.4	229.5	3.1	558.3	0.0	149.0
Leg, R		117.2	194.6	30.4	709.4	0.5	178.0

[a] Sprayers: NX,SE = 'Nomix' with serrated disc
NX,SQ = 'Nomix' with square disc
TRANS = 'Transformer' sprayer
CP = CP15 with 'Polyjet' yellow nozzle

Overall mean wind speeds for trials: Trial 3 - 3.6 m/s, Trial 4 - 3.7 m/s, Trial 6 - 2.4 m/s.

conventional spraying system of common useage. However, it should also be emphasised that the levels of both operator contamination and spray displacement were in general low, considering the somewhat marginal wind speeds that were chosen for some of the trials.

The data for spray displacement at present give only relative differences between spraying systems, although wind tunnel experiments are being carried which should make it possible to relate data obtained with these collectors to absolute quantities of spray drift.

The contamination of the lower leg sections were the highest, but these regions would normally be protected by the use of rubber wellington boots. It may be concluded that these are perhaps the most important items of protective clothing for this kind of spraying, and that they should be washed regularly, and immediately on completing spraying.

A true assessment of the toxicological risk from pesticide applications requires a knowledge of both the potential exposure, as described in this paper, and the processes of absorption and metabolism of the pesticides. The approach of Chester (1988), using clinical and biochemical monitoring to develop predictive models of chemical hazard, offers the potential to make full use of exposure data of the kind recorded here, to ensure the continued and safe use of herbicide technology in weed control.

Nevertheless, studies of the kind described here provide data on the relative safety of spraying systems by convenient and reliable methods, thus encouraging the rapid development of safer spraying techniques.

ACKNOWLEDGEMENTS

The trials described in this paper were funded by B.P. Oil Ltd (Trials 1 and 2), Monsanto (Trials 3 and 4), Chipman Chemicals/Nomix (Trial 5) and Ciba-Geigy (Trial 6), and I wish to thank these companies for their support and for permitting me to publish this information. I am also grateful for the help of several colleagues at ICAP, Cranfield, especially John Wyatt, Carol Cairns, Liz Chadd, and Nick Major.

REFERENCES

Abbott, I.M., Bonsall, J.L., Chester, G., Hart, T.B. and Turnbull, G.J. (1987) Worker exposure to a herbicide applied with ground sprayers in the United Kingdom. *American Industrial Hygeine Association Journal*, **48**, 167-175.

Bury,C.J.G. (1987) A comparative study of the drift hazard presented by contrasting ground-spraying systems. *MSc Thesis, Cranfield Institute of Technology.*

Chester, G. (1988) Pesticide applicator exposure - Towards a predictive model for the assessment of hazard. *Aspects of Applied Biology 18*, 331-343.

THE USE OF AIR ASSISTANCE IN A FIELD CROP SPRAYER TO REDUCE DRIFT AND MODIFY DROP TRAJECTORIES

W.A. TAYLOR, P.G. ANDERSEN

Hardi International, 38 Helgeshoj Alle, 2630 Taastrup, Denmark

S. COOPER

Harper Adams Agricultural College, Newport, Shropshire, UK

ABSTRACT

The consequence, in particular on spray drift, of a new principle based on an air curtain that follows closely the conventional spraying swath is described. Field data shows that angling the air curtain rearwards with flat-fan nozzle use, can reduce drift over stubble by 60%. Drift from small nozzles applying c.100ℓ/ha is comparable to conventional larger nozzles applying c.200ℓ/ha when air assistance is used. Drift is increased with wind speed but this quantity is reduced with air assistance to be comparable at 8.5m/sec wind to that derived under existing 'safe' conditions. Increasing (4 to 10km/h) spraying speed increases spray drift when air assistance is not used but retains it to a near constant amount when it is. The effect of air assistance on drift reduction when spraying cereals is still more pronounced. Quality of spray distribution is not affected by air assistance but recovery levels may be increased. Lateral displacement of spray in a cross wind is decreased with air assistance. Inflight measurements of drops show that the air curtain increases their speed - more so with the smaller and less with the larger drops. Trajectories of sprayed drops within a wheat canopy can be manipulated to deposit more spray on a vertical surface.

Environmental and economic pressures on pesticide use have spurred the development of techniques that will reduce drift and increase opportunities to ensure peak pest control with agrochemicals. Enormous resource has focussed on novel drop formation devices, those that may modify drop trajectories (for example by electrical charging) and mechnical systems that physically open the crop canopy to improve penetration. Despite these developments, hydraulic nozzle spraying remains almost always the most effective, and certainly the most reliable, way of using pesticides (Southcombe, E.S.E. 1987). However, two restraints need to be removed. In the first instance, hydraulic nozzles produce small, low momenta drops that are prone to drift and, secondly, some agrochemicals, for optimal biological effect, need to be targeted more effectively. For example, when spraying dense crop canopies there may be a need to deposit more active ingredient on stems towards the base. In addition, label recommendations between products may vary in their spray volume rate requirements from 80ℓ/ha to 500ℓ/ha, and drop size from fine to coarse. This capability need also be considered in machine design.

The Hardi Twin Spray System retains all the assets of a conventional hydraulic nozzle sprayer but is further refined, in particular with the use of a fan that blows air through appropriate ducting to a swath wide air slot. Air is emitted as a continuous full width curtain to follow at a fixed position relative to the nozzles. The air curtain can be angled from 30° forward to 30° backward. The in-flight spray drops are produced by normal flat fan nozzles and are intercepted by the air curtain after the 'spray pattern' is formed. Air speed, volume and directions may be selected as needed to change drop trajectories and ruffle crops when necessary to enhance canopy penetration. This paper summarizes some of the field research conducted so far with this machine.

REDUCTIONS IN SPRAY DRIFT

Measurement technique

The method used for describing and indirectly quantifying spray drift clouds is necessarily simplified (and more rapid) adaptation of that used by the Application Hazzard Unit at the MAFF Plant Pathology Laboratories (Gilbert and Bell, 1988). Two rows of masts are positioned downwind and 10m apart, beginning at the swath edge, then 6, but in later work 8m and 20m away. Pairs of pipe cleaners - on which the drifting spray droplets are collected - are mounted horizontally at 0.5m intervals from 0.5m above the ground (or crop) and to at least 3.0m. The sprayer makes multiple spray runs (often 6 - sometimes 4), each 100m long through the crosswind passing the masts. The traced spray liquid is water with Agral (a non-ionic surfactant) at 0.1%v.v and a water soluble fluorescent dye (-fluorescein at typically 100g/800ℓ.) Fluorometric measurements are made on a Perkin Elmer LS2 following well established techniques of extraction, preparations and field use. Relative quantities, size and heights of drifting spray clouds can then be measured with some confidence (Table 1). * There is a noticable effect of cloud diffusion with distance and - up to 3.0m at least - a lesser effect of height. By further calculations from surface plan areas of the pipe cleaner and sprayer emission rates, the absolute quantity of spray lost as drift from the original solution can then be derived. Data is normalised for comparisons between differing spray volume rates.

Table 1 : Effect of sampling height and distance downwind on spray drift measurements; μℓ/pipe cleaner.

		Mast position downwind:						
		Rep I			Rep II			
		0.0	8.0	20.0m	0.0	8.0	20m	Total
Sampling height,m	0.5	6.3/6.7	2.0/1.5	0.9/0.9	4.9/5.1	2.3/2.2	0.9/1.0	34.7
	1.0	1.8/5.9	2.1/1.8	1.1/1.1	5.8/5.4	1.9/2.4	1.8/1.4	32.5
	1.5	4.3/4.4	1.4/1.4	0.9/1.2	5.1/5.7	2.1/2.0	1.2/1.2	30.9
	2.0	3.2/3.3	1.4/1.5	0.8/1.1	3.3/3.4	1.5/1.5	0.9/1.0	22.9
	2.5	2.5/2.4	1.0/1.0	1.2/0.5	2.0/1.9	1.4/1.4	0.5/0.6	16.4
	3.0	1.5/1.5	0.8/0.7	0.7/0.6	1.1/1.3	1.5/1.3	0.6/0.5	12.1
Mast Totals		43.8	16.6	11.0	45.0	21.5	11.6	149.5

[Nozzles 411012 at 2.5 bar, spraying speed 4km/h; wind 4m/s at 2m; No air assistance]

Direction of air curtain

Spray machines with air assistance are least likely to control drift when spraying in the absence of much foliage and/or in a cross wind. Indeed deflection of forced air by the ground may increase drift - a problem met with some machine designs (Hislop, E. et al., 1986). Boom angling and hydraulic fan nozzle use with the Twin, reduces drift by over 60% with the boom angled back, spraying in a crosswind over cereal stubble, but lessens if the air curtain is angled vertically (Table 2).

Table 2 : Effect of boom angling and air assistance on drift control in cereal stubble; µl/mast (accumulation from 6 passes and 7 pairs of pipe cleaners at heights from 0.5 to 3.5m).

Mast position downwind;	0.0	6.0	20.0m	Total
Without air, boom angled back	9.8	4.1	1.3	15.2
With air, boom angled back	3.7	1.6	0.6	5.9
With air, boom vertical	4.1	2.7	0.7	7.5

[Nozzles 411012 at 2.5bar, spraying speed 7.7km.h; wind 1 to 1.5m/s at 2m]

Nozzle size

Conventional spraying at 200 to 230ℓ/ha is achieved with 411020 nozzles, 2.5 bar spray pressure and a speed of 7 to 8km.h. At several cereal stubble sites around Europe at wind speeds close to marginal (4.5m.s) for safe spraying (BCPC), these conventional treatments (with and without air assistance) have been compared to 411012 nozzles applying reduced volumes of 90 to 100ℓ/ha, again with and without air assistance but all other conditions, such as pressure at 2.5 bar, constant. Results have been consistent and are typified in Table 3. The smaller 411012 nozzles without air assistance produce over three times as much drift as the 411020 nozzles. With air assistance, the small quantity of spray lost as drift from the larger nozzles is still further reduced. The magnitude of effect is however greater with the smaller nozzles. It can be seen that drift with the smaller nozzles and using air assistance is at least comparable to that of the larger nozzles spraying in the conventional mode without air assistance.

Table 3 : Effect of air assistance on spray drift at conventional and lower volumes; % relative to conventional practice.

	Site 1 - UK			Site 2 - Germany		
	Spray volume	Air assistance		Spray volume	Air assistance	
Nozzle size	rate;ℓ/ha	None	Full	rate;ℓ/ha	None	Full
411020	200	100	61	230	100	50
411012	100	325	106	115	372	76
Wind speed at 2m; m/s	4.4			4.0		
Spraying speed; km/h	7.7			7.0		

Wind speed

Spray techniques that reduce drift may also allow equally safe spraying at wind speeds higher than those that are currently restrictive (4.5m/s). Drift measurements have been made over cereal stubble fields and grass land under wind speeds from nil to 8.5m/s (measured at 2m. height). Total quantities of spray deposited on the mast close to the sprayer have been used to derive values for spray drift losses as a percentage of the parent sprayed liquid. Quantities of spray lost as drift are small and if there is no wind, there are only traces of deposit on the 3.5m high vertical masts. Spray lost as drift increases with wind speed - rapidly beyond the 'safe' 4.5m/s conventional restraint (Table 4). Air assistance consistently reduces drift. Quantities of spray drifting when using air assistance at 8.5m/s wind are comparable to those at less than 4.5m/s wind without air assistance.

Table 4 : Effect of air assistance and wind speed on spray lost as drift; % of the emitted spray

Air assistance - off	1.9	1.8	3.2	4.7
- on	0.8	0.8	1.1	1.8
Windspeed at 2m height; m/sec	1.5	3.0	4.5	8.5

Nozzles 411012 at 2.5 bar and spraying speed of 7.7 km.h applying 100ℓ/ha

Spraying speed

Increasing spraying speed increases spray drift (Table 5). Sometimes speed changes produce only slight increases but sometimes it is large. The differences, for example, between 4 and 7km/h is little when compared to the effect of going from 7 to 10km/h with the 411020 nozzles. Air assistance reduces drift at all spraying speeds to an apparently constant amount for a given nozzle size, and thereby make the difference between air on/off more pronounced at higher rather than lower speed - with both the traditional and smaller nozzle sizes.

Table 5: Effect of spraying speed and air assistance on spray drift; µl/6 masts normalised to 100ℓ/ha applied.

Nozzle size	Spraying speed; km/h	Spray volume rate; ℓ/ha	Air assistance None	Full
411020	4	410	42.7	21.2
	7	230	44.6	22.2
	10	165	85.0	23.1
411012	4	200	74.8	35.9
	7	115	165.7	34.1

Spray pressure 2.5 bar; wind speed at 2m - 4m/s; field - cereal stubble.

Target surface

To ensure both uniformity of conditions between field experiments and derive values based on 'worst-fit' situations, main core spray drift field research has been derived from either cereal stubble or grassland fields. At key stages however, spray drift was measured over crops. For example, in Denmark drift was measured over winter wheat (Zadoks 36-38) in wind speeds of 2 to 4m.s (at 2m. height) in two fields - either across or down the 'tram lines'. Air assistance with small nozzles, reduced drift, to a level appreciably lower than conventional practice, when spraying over a cereal crop (Table 6).

Table 6 : Spray drift over cereals' % of drift when compared to the local conventional practice.

		Air assistance	
Nozzle size	Spraying direction	None	Full
411012	Across tramlines	148	33
411012	Down tramlines	232	26
411018	Down tramlines	100	26

Spray pressure - 2.5 bar; air curtain - vertical.

ANCILLARY ON-GOING FIELD RESEARCH

Spray distribution Delivery of drops to all target surfaces in adequate numbers, frequency and reliability, is the prime requirement of good spraying. The quality of this spray distribution must not be impared by, for example, the development in drift control techniques. Dynamic measurements of spray deposit variability are based on large areas (often 2m by 3m) that comprise many small grids of targets (typically 140, each 25cm2). By comparing values within and between large areas, we can predict both micro and macro variability. The quality of spray distribution was maintained and it was noted that frequently air assistance has measurably increased the mean deposit applied (Table 7). This increase is directly related to the spraying conditions and is, under favourable conditions, relatively small. However, under adverse conditions, for example when sampling deposits just within the upwind swath edge, or after spraying in higher wind speeds, this increase is larger.

Table 7 : Effect of air assistance on spray deposit variability and mean applied deposit.

Air assistance	None	Full
Mean spray deposit;ℓ/ha	96	122
Coefficient of variation;%	28.8	32.8

Nozzles - 411012 at 2.5 bar; Spraying speed - 6.5km/h; emitted spray volume rate - 125ℓ/ha

Lateral displacement of swath

Wind may not only cause small inflight drops to be carried away as drift, but may also move larger - but still sedementing - drops downwind. Problems in swath matching or contaminating hedges, rivers and other environmentally sensitive areas, can arise. To measure the effect of air assistance on this spraying feature, 5cm wide strips of chromatography paper are placed to extend from under the spraying swath (to measure the applied deposit), through the swath edge (to describe the swath shoulder) and downwind (to measure the displaced deposit). Our results show that air assistance reduces downwind displaced spray and maintains the 'shoulder' pattern (Table 8).

Table 8 : Effect of air assistance on swath displacement;
μl /25cm2 (mean of 3 replicates)

	Under sprayed swath					Swath edge				
Without air assistance	18.6	18.3	16.7	18.6	16.1	16.2	18.4	15.6	11.7	10.9
Downwind displacement	4.7	3.8	4.6	3.8	3.2	2.5	2.0	1.6	1.0	1.2
	Under sprayed swath					Swath edge				
With air assistance	18.8	21.7	24.3	21.0	25.4	22.8	20.0	14.8	13.7	9.4
Downwind displacement	0.7	0.9	0.4	0.5	0.6	0.5	0.5	0.4	0.2	0.2

← 2.0m →

Windspeed; 1 to 1.5m/sec →

411012 nozzles at 2.5 bar; spraying speed of 9km/h; spray volume rate emitted was 90ℓ/ha.

In-flight drop characteristics

A Particle Measuring System (PMS) has been used in the field to measure inflight drop size, velocities and numbers. The Twin was stationed facing the wind with the PMS probe positioned 0.5m vertically below at several points through the full depth of the spraying swath, and measurements made with and without air assistance. The data was compared with identical nozzles similarly characterised under laboratory conditions. The Volume Median Diameter of this nozzle (411012 at 2.5 bar) under all conditions was 250μm. The effect of air assistance on drop speeds is in proportion to drop size, increasing their relative speeds with smaller sizes (Table 9). The consequences of this effect is to increase the number and hence total volume of small drops sampled by the probe (Table 10) - demonstrating that the air curtain can maintain and protect small drop momenta.

Table 9 : Effect of air assistance on drop velocity; m/s

	Indoors	Outdoors	
		Without	With air assistance
Drop size; µm 100	2.2	1.6	4.3
200	2.7	2.4	6.2
300	7.3	5.7	9.7
400	9.7	7.9	11.3
500	12.5	11.7	12.8

Ambient windspeed - 1.5m/s at boom height.

Table 10 : Spray volume fractions comprised of drops less than 150µm at 0.5m below nozzle; %

Air assistance	
None	Full
0.4	6.4

Crop canopy penetration

Using unaided hydraulic nozzles to apply differing volume rates and drop sizes, offers few, if any opportunities to manipulate spray deposits within cereal canopies (Taylor and Andersen, 1987). The use of an air curtain may mitigate this restraint but measurement techniques need be carefully chosen. For example, falsely low readings can be taken if flat rigid surfaces - such as 5cm. wide chromatography paper - are raised off ground level and sprayed with high air speeds. The air entrained spray drops are forced past such a target and fail to impact. Relevant techniques have now been developed and appraised for measuring air assisted sprays within crop canopies. Applied and available in-flight drops are non-intrusively sampled using pipe cleaners - as in the drift studies. These targets may be typically positioned at crop height in the horizontal plane to assess applied deposits or horizontally and vertically at predetermined heights within the canopy. In spray accountability studies, it is valuable to measure ground spray deposition - which for foliar acting products could indicate waste rather than reflect efficiency of crop canopy penetration. In addition, spray deposits are measured on plants either complete or sectioned into relevant target zones.

This work is still in rapid progress and experimentation will need be far ranging and thorough if our conditions of use are to offer maximum advantages to the user. Machine variables under the operator's control need to be matched to the equally variable developing crop or changing weather conditions. Despite these challenges simple patterns of performance are evident. For example, spraying winter wheat at two growth stages show how air assistance modifies drop trajectories to alter ratios of spray deposits captured on horizontal (fixed 14cm above ground level) and vertical (fixed at ground level and 14cm high) pipe cleaners (Table 11).

Table 11 : Trajectory of spray drops within a developing wheat crop; ratio of horizontal/vertical deposits.

Boom angled :	Back		Vertical		Forward	
Air assistance :	None	Full	None	Full	None	Full
Zadoks 31	2.6	1.6			3.3	2.3
34	2.7	1.6	4.6	1.5	3.5	0.8

High ratios indicate more deposit pro rata on horizontal rather than vertical targets. Conversely, low ratios indicate more lateral drop movement with higher deposits on vertical surfaces.

Measurements of ground deposits, show equally encouraging opportunities for spray deposit manipulations (Table 12). Air assistance can reduce ground deposits, an effect attributable to the cereals layering over each other as the air curtain moves above.

Table 12 : Spray deposition at ground level within a wheat crop (Zadoks 32);ℓ/ha

		Air assistance		
Boom angle :		None	Half	Full
	Back	29	18	19
	Forward	25	11	16

Nozzles - 411012; spray pressure - 2.5 bar; spraying speed - 7.7km.h; spray volume rate - 100ℓ/ha.

DISCUSSION

It can be seen that an appropriately designed machine with air assistance can substantially reduce drift under a very wide range of operational, cropping and environmental conditions. Use of small nozzles, faster spraying speeds and safer spraying in higher wind speeds will be possible. The success of this technique is dependent on the full width air curtain that follows the spraying swath, intercepting the drops from a flat fan nozzle only after their inflight 'pattern' is formed. This unique configuration ensures optimal spray distribution and drift control. Thus conventional hydraulic nozzle use, whose physical and biological performance are well established, can be used to still further advantage. The range of volume rates and drop sizes needed to satisfy agrochemical trade label and regulatory advice is easily and reliably obtained. In addition, the form of the sprayed deposit - especially drop size, numbers and concentrations, is not altered and should not exasperate problems, for example, in crop selectivity or operator contamination. The future for manipulating spray deposits to more effective - or from less desirable - target sites is exciting; already we can see in cereals, for example, opportunities to apply more laterally moving drops in the lower zones of the crop, as and when required. Hence drop trajectory as well as drop size, numbers and speeds become an operator controlled feature of agrochemical spraying.

We conclude that the Twins Spray System enables operators to spray with greater precision in pesticide timing by being more effective in the field by both using the lower volume rates currently recommended and spraying under a greater range of wind speeds to improve work rates. Opportunities for dose reduction will stem mainly from the improved timing in application and, in part, by better targeting of sprays.

ACKNOWLEDGEMENTS

Much resource and a dedicated team effort has been channelled into the work outlined in this paper. The authors are grateful to colleagues for this support. In addition, we have considerably benefitted from the expertise and help of Mr. B. Young and N. Fletcher of ICI Agrochemicals at Jealotts Hill Research Station in Bracknell, and Mr. A. Lavers and Dr. C. Cowell of Shell Research, Sittingbourne. Guidance on techniques, methodology and interpretation of results has been generously offered by Dr. A. Gilbert at the MAFF Plant Pathology Laboratory, Harpenden and Dr. P. Miller at the AFRC Engineering, Silsoe, Bedford.

Our thanks are also extended to Mr. R. Terry of Red House Farm, Chapel End, Nuneaton and Mr. G. Furness of Caynton Manor Farm, Newpoert, Shropshire who patiently allowed us to use their fields and crops on so many occasions.

REFERENCIES

Gilbert, A.J. and Bell, G.J. (1988) Evaluation of the drift hazards arising from pesticide spray application. Aspects of Applied Biology 17, 1988. Environmental aspects of Applied Biology.

Hislop, E.; Cooke, B.; Herrington, P.; Western, N. and Woodley, S. 1986, 48-49. Efficient use of Agrochemicals AFRC Institute of Arable Crops Research - Long Ashton Research Station Annual Report 1986, 48-49.

Miller, P.C.H.; Walklate, T.J. and Mower, C.J. (1989) A comparison of spray drift collection techniques. BCPC Weeds - 1989

Southcombe, E.S.E. (1987) Developments in application techniques. Royal Agricultural Society of England; NAC Conference.

Taylor, W. and Andersen, P.G. (1987) Effect of application changes and cereal growth stage on spray deposition. Aspects of Applied Biology 14, 1987. Studies of pesticide transfer and performance, 71-76.

COMPARATIVE DRIFT MEASUREMENTS FOR BCPC REFERENCE HYDRAULIC NOZZLES AND FOR AN AIRTEC TWIN-FLUID NOZZLE UNDER CONTROLLED CONDITIONS

N.M. WESTERN, E.C. HISLOP, P.J. HERRINGTON, E.I. JONES*

Department of Agricultural Sciences, University of Bristol,
AFRC Institute of Arable Crops Research, Long Ashton Research Station,
Bristol BS18 9AF, UK. * Sandwich Student, Manchester Polytechnic

ABSTRACT

A wind tunnel has been used to measure spray droplet drift from the BCPC spray classification scheme reference nozzles and an Airtec twin-fluid nozzle. For both types of nozzle, drift increased linearly with increasing wind speeds and with increasing fineness of spray quality. An empirical model which describes drift from reference nozzles using only wind speed data and the percentage of spray volume in droplet size classes less than 50 µm is derived. Drift from the Airtec nozzle did not fit the model which grossly overestimated drift compared to measurements. For many combinations of air and water pressure the twin-fluid nozzle produced less drift than medium spray quality hydraulic nozzles, but some combinations which produced potentially driftable sprays are identified. Results obtained in the wind tunnel compared favourably with data from other sources.

INTRODUCTION

The Airtec$^{(R)}$ twin-fluid nozzle developed by Cleanacres Machinery Ltd is unique amongst arable spray atomisers in that flow and atomisation are a function of independently variable air and water pressures. Prototype nozzles of this design were used by Cowell & Lavers (1987) to examine the spectrum of drop sizes produced when water is atomised. They showed that the nozzle is highly versatile and suggested that it "provides an elegant means of dialling a droplet size". We had previously come to similar conclusions (unpublished data supplied to Cleanacres Ltd) but could not produce good data with a phase/doppler droplet analyser (Bachalo & Houser, 1984) when the spray liquid was a surfactant solution as used in standard British Crop Protection Council (BCPC) nozzle spray quality classifications (Doble et al., 1985).

An attempt has been made to fit sprays produced by the Airtec nozzle into the BCPC comparative spray classification scheme (Southcombe, privileged communication) prior to a full understanding of their complex nature. In part this classification appears to have been used to support a claim by the manufacturers that the Airtec spray system "dramatically reduces drift (up to 10 times over conventional systems)".

The main object of the present study was, therefore, to make comparative drift measurements under controlled conditions between the many possible combinations of flow and atomisation using the Airtec atomiser, and the BCPC standard reference nozzles, and to determine if these could be related to quantitative measurements of spray quality. A second more long-term objective was to determine to what extent our new wind tunnel could be used for comparative analysis of drift from a variety of atomising systems.

MATERIALS AND METHODS

The Airtec nozzles used were identical to those currently fitted to Cleanacres spray booms and incorporated the 35 three-hole restrictor and a steel 73 deflector. The general design of the nozzle is as described previously (Cooke & Hislop, 1987). During spraying, air pressures were maintained at 0.7, 1.0, 1.4 or 1.8 bar while water pressures were adjusted between 1.02 and 3.70 bar to give individual nozzle flow rates of 0.32, 0.42, 0.54 and 0.68 l/min as detailed in Table 1. For comparative purposes Lurmark Kemetal 110° hydraulic pressure flat fan nozzles were used as in the BCPC nozzle classification scheme, viz F110/0.45/4.5 (01), F110/0.85/3.5 (02), F110/1.44/2.5 (04) and F110/2.58/2.0 (08). The manufacturers nozzle size descriptions e.g. (01) are given because they are used as an abbreviation in Figs. 1 - 3.

All spray drift measurements were made in a spray chamber (Hislop, 1989) with the spray boom static and perpendicular to the direction of the wind. Drift was collected on horizontal Bri-nylon 2-ply knitting yarn lines (Hayfield Textiles Ltd) 7.0 m downwind of the nozzles at 5, 15, 25, 35 and 45 cm below nozzle height. Initial work was done with the chamber empty and the nozzles c. 1.5 m above the floor. Later drift measurements were made with the chamber filled with tray-grown cereal plants in ear, c. 90 cm high, in which case the nozzles were positioned 45 cm above the top of the crop with the drift collecting lines positioned as described above.

The spray solution for all drift work was 0.025% w/v sodium fluorescein and 0.1% w/v Agral 90 in tap water. Wind speeds in the tunnel were measured with a hot wire anemometer (PSI Ltd) at a reference point at nozzle height but 3.5 m downwind of the nozzles. All the work reported here was done at measured wind speeds of 2, 3 or 4 m/sec.

Fluorescein deposited on each drift collector was extracted in 0.05 M sodium hydroxide and measured. All the data presented here are the sum of the recoveries from the five sampling lines. Results are presented in terms of the weight of tracer collected (µg) per g of tracer sprayed to take account of the different volumes of spray emitted from the various nozzles used. This normalisation process is justified on the grounds that in practice whatever the spray volume used the dose of chemical per unit area of ground is kept constant.

Spray droplet sizes and velocities were measured with Aerometrics Phase/Doppler Particle Analyser to produce temporal sample data (Aerometrics Inc., USA). All measurements were made 30 cm below the nozzles. The BCPC reference nozzle data are means of three replicate measurements taken as seven slices 11 cm apart perpendicular to the long axis of the flat fans spraying water plus 0.1% w/v Agral 90 by tracking the nozzles in X and Y paths above the laser's intersection point (Lake & Dix, 1985). The recombined raw data are volume weighted according to the Aerometrics software package. Because at least 16 combinations of air and water pressure were required to describe the sprays from the Airtec nozzle, the above procedure was simplified by taking replicate long axis scans of water sprays only.

RESULTS

Wind speed measurements within the tunnel indicated that the air flow was essentially laminar. When the tunnel was empty wind speed at nozzle height was maintained at distances greater than 50 cm below the nozzles. When filled with crop, wind speeds at the top of the crop were reduced by _c_. 50% because of crop roughness but at 20 cm above the crop were reduced by only _c_. 15%.

The important drop spectra parameters for the reference and Airtec nozzles are presented in Table 1. The trends seen are similar to those of Doble _et al_. (1985) and Cowell & Lavers (1987), respectively, but differ in absolute terms because they were measuring spatial samples.

TABLE 1. Reference (A) and Airtec (B) nozzle droplet data.

				VMD	% Volume		Velocity (m/s)		
				(µm)	< 50 µm	< 100 µm	Mean	50 µm	100 µm
A.	F110/0.45/4.5 (01)			141.2	2.70	18.75	2.70	2.41	2.42
	F110/0.85/3.5 (02)			191.6	1.01	8.00	3.37	2.75	2.84
	F110/1.44/2.6 (04)			266.8	0.50	3.40	3.73	2.74	2.86
	F110/2.58/2.0 (08)			378.4	0.30	1.70	4.45	3.07	3.16
B.	Flow (l/min)	Air (bar)	Water (bar)						
	0.32	0.70	1.02	340.7	0.96	5.38	2.46	1.53	2.11
		1.00	1.35	298.8	1.69	8.15	2.99	2.18	3.24
		1.40	1.70	227.1	3.83	15.00	3.24	2.68	3.92
		1.80	2.17	175.0	7.61	24.93	3.37	3.03	4.41
	0.42	0.70	1.37	370.3	0.56	3.65	2.54	1.48	1.87
		1.00	1.60	345.6	1.10	6.05	3.13	2.04	2.94
		1.40	2.03	254.3	2.23	10.86	3.84	2.90	4.30
		1.80	2.46	218.2	4.64	17.78	3.99	3.22	5.22
	0.54	0.70	1.90	447.9	0.28	2.01	2.66	1.39	1.77
		1.00	2.18	365.1	0.63	4.26	3.13	1.90	2.37
		1.40	2.58	284.9	1.58	8.42	3.77	2.62	3.74
		1.80	3.00	247.9	2.84	12.15	4.23	3.25	4.92
	0.68	0.70	2.60	514.8	0.13	1.22	2.82	1.32	1.62
		1.00	2.92	401.1	0.37	2.74	3.13	1.78	2.40
		1.40	3.30	329.7	0.88	5.42	3.85	2.57	3.31
		1.80	3.70	291.4	1.44	7.64	4.38	3.15	4.28

The difference between spatial and temporal samples has been discussed by Frost & Lake (1981).

Figure 1 shows a plot of Airtec volume median diameters against flow rates and air pressures. A plot of mean drift values measured 7 m downwind for a wind speed of 4 m/s in an empty tunnel is shown in Figure 2. Comparison of these data with the corresponding droplet size data in Table 1 indicates that there is a relationship between decreasing droplet sizes and increasing drift even though the compositions of the spray solutions used were different.

Figure 3 records mean drift values over a tray-grown wheat crop from the BCPC reference nozzles and selected Airtec nozzle settings plotted against wind speed. The drift values for the individual reference nozzle tests were subjected to analysis of variance and regression lines for wind speed fitted for each nozzle. The slopes and intercepts of these lines were then plotted against droplet size variates (VMD, NMD, % vol. < 50 or < 100 µm, log (% vol. < 50 µm) to find the best descriptive variate.

This empirical approach indicated that the log of % volume in drop size classes less than 50 µm was best. The simple model takes the form:

$$\text{Drift } (\mu g/g) = 251\ (-4.35 \times \log \%\ \text{vol} < 50\ \mu m) + 1.244\ (\text{wind speed}) + \log\ (\%\ \text{vol} < 50\ \mu m) \times \text{wind speed}$$

and, although significantly worse than fitting separate straight lines represents the data reasonably well with the least satisfactory non-linearity shown by the largest nozzle (F110/2.58/2.0 (08)).

DISCUSSION

Our results suggest that a wind tunnel is capable of yielding sensible comparative data of relative drift potentials of different spray nozzles. This claim is supported by the fact that insertion of our BCPC nozzle droplet size data into the preliminary drift model of Miller & Hadfield (1989) produced predicted drift lines remarkably similar in slope and separation to those we measured. However, the absolute values for drift were different and the reasons for this are being examined. Additional encouragement comes from the limited field data available for the Airtec/hydraulic nozzle comparisons reported to Cleanacres by Miller & Mawer (1989) which again indicate reasonably good agreement with our results.

Drift measurements were not always well reproduced in replicate tests. In part this might be due to difficulties in accurately adjusting wind speeds since three different hot wire anemometers gave somewhat different readings. In addition, some high air temperatures of up to 31°C made experimentation difficult. Despite such problems, two sets of drift data for the reference hydraulic nozzles (one obtained when the tunnel was empty compared with when full of crop) were analysed statistically. The results were similar and both suggested that the droplet parameter measuring the percentage of spray volume in drop size classes less than 50 µm was slightly better than the % $<$ 100 µm. However, the general conclusion that droplet drift is largely a function of the number of small drops in a spray and of wind speed is predictable and agrees with the field results of Lloyd & Bell (1984).

Figure 1. Plot of volume median diameters of Airtec sprays (——) compared to those of reference hydraulic nozzles (- - -).

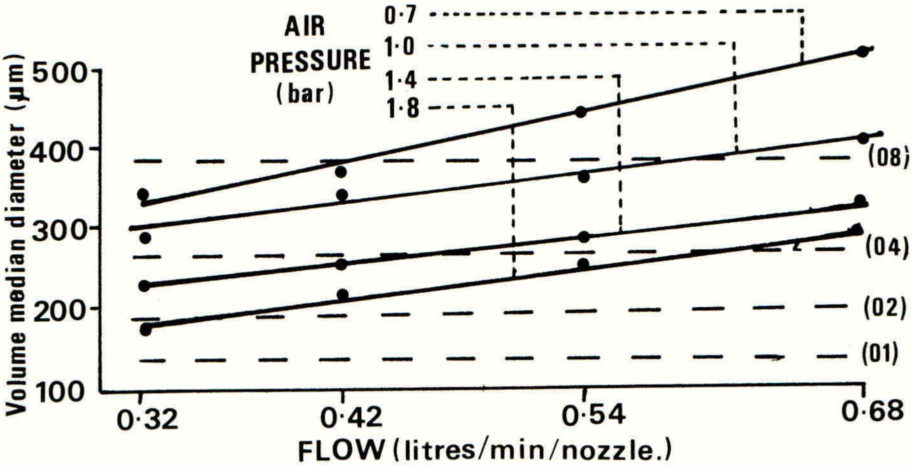


Figure 2. Drift at 7m (tunnel empty) of Airtec (——) and reference hydraulic nozzles (---) for a wind speed of 4m/sec.

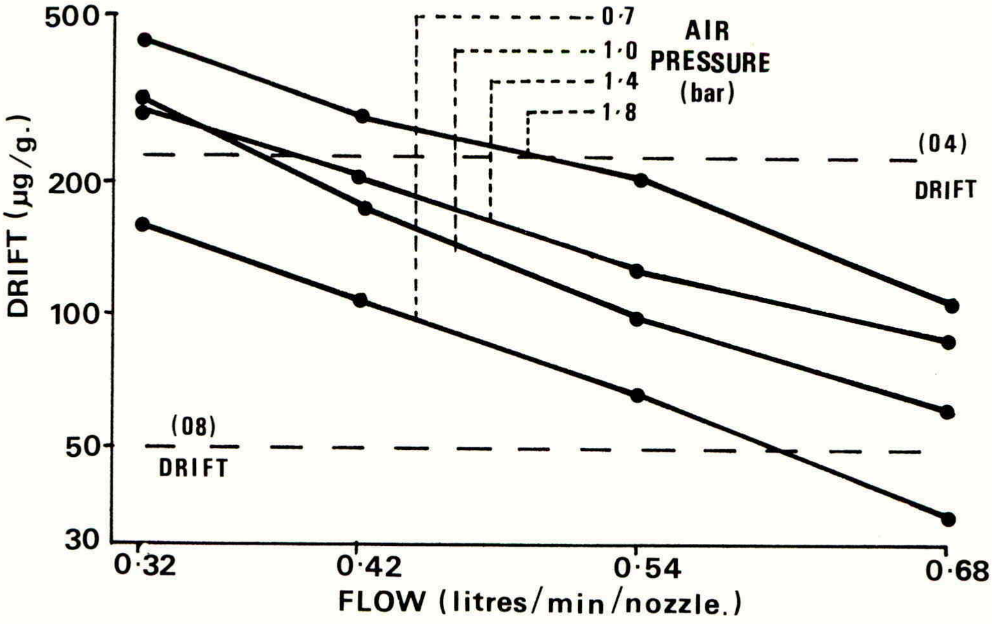
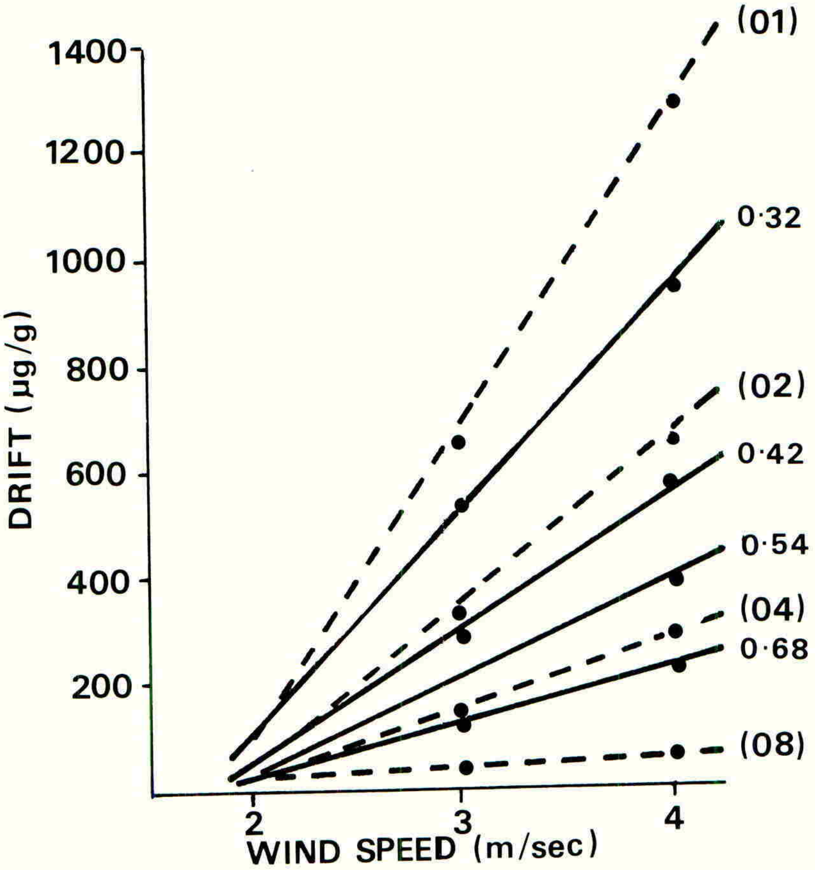


Figure 3. Drift at 7m (over a wheat crop) for reference hydraulic nozzles (---) and Airtec nozzles operating at 1.8 bar air pressure and stated flows (——, l/min).



The Airtec nozzle is indeed a versatile atomiser and at many settings of air and water pressure produces spray drift similar to medium or coarse reference hydraulic flat fan nozzles. However, as illustrated in Figures 2 and 3, it cannot always be described as a non-drifting nozzle and the settings to avoid are high air and water pressures to give a low flow rate. But a flow of 0.32 l/min from an air pressure of 0.7 bar produced less drift than the medium quality reference hydraulic nozzle (F110/1.44/2.5). Of greater practical significance were drift measurements from air/water pressures of 0.7/c. 2.6 bar respectively, to give a flow per nozzle of 0.68 l/min, and drift similar to the coarse (08) hydraulic nozzle (data not reproduced in Fig. 3) but as indicated in Figure 2. This flow rate equates to an application volume of c. 100 l/ha and if lack of Airtec drift is due to similarities in the mass of spray droplets from the two nozzles, this type of spray could be too coarse for optimal biological performance of some pesticide sprays now often made with such volumes.

Substitution of the Airtec small droplet data obtained for water sprays into the simple empirical model developed for the reference nozzles grossly overestimates drift compared to measured values. However, as a twin-fluid nozzle, air issuing with the spray probably reduces the effects of wind. Reference to the small droplet velocity data in Table 1 shows that these are sometimes a little greater than comparable hydraulic nozzle droplets, but the significance of this is unknown. The observation by C.R. Merritt (reported by Miller & Mawer, 1989) that "spray becomes airborne as a result of vortex interactions at the edge of the liquid sheet with spray from conventional hydraulic nozzles and that the behaviour with spray from the Airtec nozzle was substantially different" may be of considerable importance.

Our results indicate that spray drift does not occur at wind speeds less than c. 1.5 m/sec (Fig. 3) and they reflect the field measurements of Lloyd & Bell (1984) and Miller & Mawer (1989). However, our wind flow is laminar and constant unlike natural wind and our spray boom is static and at a constant height in contrast with a field application. We have measurements confirming that drift is much influenced by spray release height as discussed by Miller (1988).

Comparative spray drift measurements under controlled conditions are very much simpler to perform than field measurements, but are not necessarily a substitute. The final goal should be the development of a reliable predictive model; our data produced in a very different manner from that of Miller & Hadfield (1989), may be of value in achieving this objective.

ACKNOWLEDGEMENTS

We gratefully acknowledge the assistance of Dr P. Miller in giving us access to his computer model, and the statistical help of Ms Ruth Butler and Dr P. Brain.

REFERENCES

Bachalo, W.D.; Houser, M.J. (1984) Phase/doppler spray analyser for simultaneous measurements of drop size and velocity measurements. Optical Engineering **23**, 583-590.

Cooke, B.K.; Hislop, E.C. (1987) Novel delivery systems for arable crop spraying - deposit distribution and biological activity. Aspects of Applied Biology, Studies of pesticide transfer and performance **14**, 53-70.

Cowell, C.; Lavers, A. (1987) A laboratory examination of two prototype twin-fluid spray nozzles. Aspects of Applied Biology, Studies of pesticide transfer and performance **14**, 35-52.

Doble, S.J.; Matthews, G.A.; Rutherford, I.; Southcombe, E.S.E. (1985) A system for classifying hydraulic nozzles and other atomisers into categories of spray quality. Proceedings of the British Crop Protection Conference - Weeds 1985 **3**, 1125-1133.

Frost, A.R.; Lake, J.R. (1981) The significance of drop velocity to the determination of drop size distributions of agricultural sprays. Journal of Agricultural Engineering Research **26**, 367-370.

Hislop, E.C. (1989) Crop spraying under controlled conditions. *Comparing laboratory and field pesticide performance*. *Aspects of Applied Biology* **21**, 119-120.

Lake, J.R.; Dix, A.J. (1985) Measurement of droplet size with a PMS optical array probe using an *x* - *y* nozzle transporter. *Crop Protection* **4**, 464-472.

Lloyd, G.A.; Bell. G.J. (1984) Hydraulic nozzles: comparative spray drift study. MAFF report of a study carried out in 1983 in association with the British Agrochemical Association, 41 pp.

Miller, P.C.H. (1988) Engineering aspects of spray drift control. *Aspects of Applied Biology*, *Environmental aspects of applied biology* **17**, 377-384.

Miller, P.C.H.; Hadfield, D.J. (1989) A simulation model of the spray drift from hydraulic nozzles. *Journal of Agricultural Engineering Research* **42**, 135-147.

Miller, P.C.H.; Mawer, C.J. (1989) Comparative spray drift measurements from a twin-fluid nozzle. Report of work contracted by Cleanacres Ltd (and supplied by them).

A CLOSED SYSTEM FOR LIQUID PESTICIDE TRANSFER

A. LAVERS

Shell Research Limited, Sittingbourne Research Centre,
Sittingbourne, Kent, ME9 8AG.

ABSTRACT

Transferring liquid pesticide from product container to spray tank is potentially the most hazardous task undertaken by the spray operator. In order to protect the operator from the product during the liquid transfer process a prototype Closed System has been developed by a Chemical Industry working group. The device, under test, has proved that it can transfer viscous materials from container to spray tank and that it can be adapted to rinse the empty container efficiently. The Closed System described is free standing and can accommodate containers up to 12 litres capacity. Chemical dosing is controllable and excess formulation can be returned to its original container. The extensive testing of the system has clearly illustrated the importance of formulation viscosity in determining performance and the urgent need for container and closure standardisation.

INTRODUCTION

Transferring liquid pesticide product (concentrate) from its original shipping container to the spray tank is potentially the most hazardous task undertaken by the agricultural spray operator. Specialised clothing affords a degree of operator protection but it would be preferable to contain any potential hazard at source. The engineering problems associated with the safe isolation of the liquid transfer process are often further exacerbated by the disparity between both chemical container design and closure size. Closed chemical transfer systems were introduced in California in 1973 following widespread concern over worker exposure to agrochemicals when handling concentrate material. However, the inadequacy of early transfer systems made compliance with the law extremely difficult.

The acceptance by industry in California of Closed Transfer Systems has clearly resulted in a significant reduction in worker illness related specifically to pesticides handling. (Table 1.) (Brazelton R.W. and Akesson N.B. 1987). Many systems, both sealed and partially sealed are available currently in the United States of America, but in Europe chemical transfer from container to spray tank is confined to suction probes or induction bowls (Frost A.R. and Miller P.C.M. 1988). Working from design criteria agreed by a Chemical Industry working group, the Battelle Institute produced a prototype chemical transfer system which was evaluated for transferring a selection of viscous formulations from container to spray tank. Table 2 lists the design considerations for a sealed transfer system which the manufacturers incorporated into the prototype. This report outlines a representative selection of results obtained from a considerable number of trials conducted in Europe to evaluate the transfer and rinse capabilities of the prototype transfer system.

METHODS AND MATERIALS

The Closed Transfer System

The Closed Transfer System (CS) is a free-standing unit designed to accept chemical containers of up to 12 litres capacity with varying closure diameters. It is plumbed into the liquid by-pass hose returning from the sprayer control unit to the spray tank. The CS consists of five major components (Figure 1).

1. Chemical container attachment

The chemical container fits onto an adjustable platform which when raised squeezes the container closure against a concave VITON* sealing ring. The container is then rotated through 180° and the formulation is measured into the glass container. Figures 2a and b illustrate the fitting of the chemical container.

2. Glass measuring tube

A cylindrical graduated glass tube is connected to the container via a dosing valve, which controls the formulation flow into the measuring cylinder.

3. Integrated rinsing system

A rotating nozzle is fitted to a telescopic tube which is lifted by water pressure up into the chemical container when in the inverted position. When the water pressure is reduced the telescopic tube reverts to its original position within the glass cylinder. Valve activation enables only the measuring cylinder to be rinsed if the chemical container is not empty.

4. Control valves

The control valves regulating the water flow have been designed to prevent accidental mis-use.

5. Venturi

To evacuate the liquid from the transfer system to the sprayer a venturi is fitted in the liquid bi-pass hose and requires a flow-rate in excess of 45 l/min to empty the chemical container. Depending on the viscosity of the formulation it takes between 15 and 20 seconds to empty a 5 litre container followed by a further 5 seconds to transfer the liquid to the spray tank.

Rinse test procedures

The primary objective was to determine the efficiency of the equipment to rinse the transfer system and chemical containers; accuracy of dose delivery and transfer were secondary considerations.

---

*VITON is a Dupont trade mark.

A series of rinse tests were conducted with viscous suspension concentrate (SC) formulations in an attempt to determine ability of the device to rinse empty containers to an acceptable standard. (e.g. Netherlands - <0.01% of the original container contents remaining after rinsing, equivalent to <1 ml for a 10 litre container.)

The CS was connected to a field sprayer fitted with a 600 litre tank and a diaphragm pump with an output of 120 l/min at 3 bar pressure. The rinse tests were carried out at Limburgerhof in West Germany. Full chemical containers were shaken for 5 seconds then emptied and drained at an angle of 45° for a further 30 seconds. The closure caps were rinsed separately. Different rinsing cycles were evaluated using clean water, or field strength spray solution for various rinse times.

Hand rinsing was included in some trials for comparison (Table 3). After rinsing, containers were drained for a further 30 seconds, then refitted with a clean cap and removed to the laboratory for residue analysis. The analysis was carried out by laboratories associated with the respective products, e.g. cyanazine at Sittingbourne Research Centre, and the methods used were standard procedures for the compounds concerned; details can be obtained from the relevant companies.

<u>Containers</u>

A number of containers, selected to cover a range of current designs, were used for the emptying and rinse tests. They varied in capacity but were generally either 5 or 10 litres and made of HDPE.

RESULTS

Table 3 lists a representative selection of the results from manual rinsing tests, illustrating that the chemical residue remaining in the container is often unacceptable, and the process may be time consuming for those products for which excessive residues are found. The residue of product remaining in the container when rinsing with spray solution is shown in Table 4. These figures are relevant to field practice where containers may be rinsed with spray solution when a supply of clean water is unavailable. Table 5 lists a selection of chemicals that are considered to be difficult to remove in a rinse cycle, and clearly illustrates that, with the exception of clofentezime, the Closed Transfer System can achieve acceptable container rinsing results when using clean water.

DISCUSSION

The representative selection of experiments repeated here have shown that, for a range of formulation viscosities, 5 litres of product can be metered and introduced into the spray tank within 25 seconds. The rotating water nozzle on the telescopic tube has improved rinse efficiency over the original static nozzle and some containers have been left essentially (beyond detection limits) free from product residues following rinsing.

Rinsing for 60 seconds with clean water has kept chemical residues below the limit of 0.01% of the original amount of material in the pack, and many containers have been satisfactorily rinsed with shorter rinsing intervals. In cases where <0.01% residue has not been achieved, the failure can be accounted for in terms of high formulation viscosity and/or peculiarity of container design. Where field strength spray solution has been used as the rinsate, container residue levels have not always been acceptable. The use of clean water from an integrated spray tank for rinsing would therefore be preferable. A comparison of rinse efficiency against manual rinsing confirms the system is capable of efficient container decontamination. However, efficient cleaning is only possible where the container shape allows the rinsate to cover all inner surfaces, and to drain quickly. Thus, containers with hollow handles will always be difficult to rinse efficiently. Equally, fluorinated containers have proved to be easier to rinse than their untreated equivalents. The establishment of an effective seal between the chemical container and the measuring vessel has been problematical because of the many container closure sizes, but a recent industry recommendation to standardise 5-20 litre container closures at 63 mm will alleviate this problem.

CONCLUSIONS

The prototype Closed Transfer System described can transfer viscous formulations rapidly from container to spray tank and rinse the empty container. Compared with hand pouring, the CS may be considered slow, but the system achieves the objective of safe liquid transfer and has the facility to return excess formulation to its original container. Further design refinement of the sealing mechanism between the chemical container and the transfer device will be necessary to ensure different container closure sizes can be accepted. However the standardisation of closure size will assist design improvement.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the contributions to this project made by representatives of BASF, FRG., Bayer FRG., Giba-Geigy Ltd., Switzerland, Hoechst, FRG., ICI. UK., Rhône-Poulenc, France, Sandoz, Switzerland, Schering FBC Ltd., UK and Shell International Chemical Company Ltd., UK. The above companies are all members of the working group responsible for developing the Closed Liquid Transfer System.

REFERENCES

Brazelton, R.W.; AKESSON, N.B. (1987). Principles of Closed Systems for Handling Agricultural Pesticides. Pesticide Formulation and Application Systems. 7th Volume. ASTM STP 968.

Frost, A.R.; MILLER, P.C.M. (1988). Closed Chemical Transfer Systems. Div. note DN1448 AFRC Institute of Engineering Research Silsoe. Jan. 1988.

Table 1 - Reported mixer/loader illness related to handling Pesticides compared with the total pesticide related illnesses from 1975 to 1985 (California)

	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985
Mixer Loader	143	122	143	142	132	123	124	127	96	85	78
Total Cases	1443	1452	1518	1194	1019	1402	1093	1334	1270	1156	1516
% of Total	10.6	8.4	9.4	11.8	12.9	8.7	11.3	9.5	7.5	7.3	5.1

Table 2 - Design criteria for a closed liquid pesticide transfer system

1. Contamination-free opening and emptying of a range of chemical containers.
2. Capable of withdrawing measured dose from chemical container.
3. Capable of returning excess chemical to original container.
4. Dosing accuracy better than ± 10% for all chemical viscosities.
5. Readily adapted to existing spray equipment.
6. Capable of accepting a wide selection of container and closure sizes.
7. Secure sealing to avoid contaminating containers, spray components and operations.
8. Capable of meeting approved rinse standards for empty containers.
9. Controls designed for foolproof operation.
10. Materials used for construction must be compatible with a wide range of formulations.

Table 3 - Results from manual rinse tests

Treatments SC formulations	HDPE Container size litres	Rinse liquid	Rinse time seconds	Residue remaining % of original product
Cyanazine/Atrazine	5	2.5 l clean water	3 x 10	<0.002
Cyanazine/Atrazine	5	2.5 l clean water	5	0.031
Flutriafol/ Chlorothalonil	5	2.5 l clean water	5	0.048
Clofentezime	10	2.5 l clean water	5	0.002
Vinclozolin	5	1 l distilled water	3 x 30	2.78
Vinclozolin	10	1 l distilled water	3 x 30	1.62

Table 4 - Results from mechanical rinse tests using spray solution as rinsate

Treatments SC formulations	HDPE Containers size litres	Rinse liquid	Rinse time seconds	Residue remaining % of original product
Vinclozolin	10	Spray solution 3%	60	0.0130
Vinclozolin	10	Spray solution 1.5%	60	0.0040
Fluatriafol/ Carbendazim	5	Spray solution 3%	60	0.0174
Cyanazine/ Atrazine	5	Spray solution 3%	60	0.2941
Clofentezime	10	Spray solution 2%	60	0.0040
Diflufenican/ Isoproturon	5	Spray solution 2%	60	0.8000

Table 5 - Results from mechanical rinse tests using clean water as rinsate

Treatments SC formulations	HDPE Containers size litres	Rinse liquid	Rinse time seconds	Residue remaining, % of original product
Vinclozolin	10	Clean water	60	0.0032
Clofentezime	5	Clean water	60	0.0160
Isoproturon	5	Clean water	60	0.0002
Nicotine	5	Clean water	60	0.00004
Chlortoluron	10	Clean water	60	0.0010
Simizine	5	Clean water	60	0.0040
Alconifen	10	Clean water	60	0.00007
Cyanazine	5	Clean water	60	0.0020

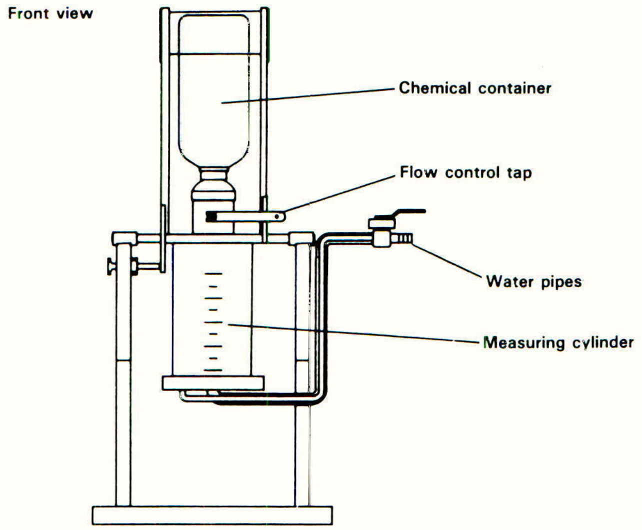


Figure 1
Diagram of closed transfer system

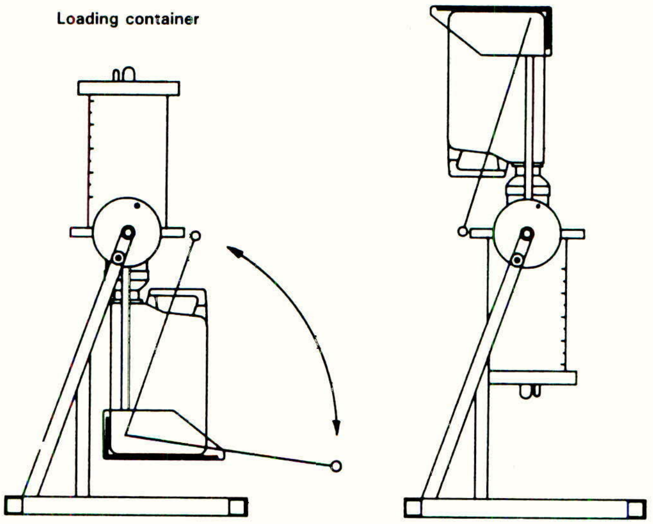


Figure 2
Fitting the chemical container to the closed transfer system

A NOVEL SYSTEM FOR SAFE AND EFFECTIVE HERBICIDE APPLICATION

R. DAWSON, T. ROBINSON, A. DU.RIEU, P.J. RYAN

Ciba-Geigy Agrochemicals, Whittlesford, Cambridge, CB2 4QT

ABSTRACT

The Transformer Spraying System has been developed for the accurate application of pesticides with minimum hazard to the operator, the environment and non-target areas. This has been achieved through the combination of novel packaging, pressure regulation and nozzle design. The System has been evaluated over two years in comparison to conventional knapsack sprayers for the contact and residual control of annual and perennial weeds.

INTRODUCTION

Conventionally packed herbicides applied through knapsack sprayers present the spray operator with several problems. First there is often difficulty in calculating the correct dose to add to the sprayer in order to achieve the desired application rate. Secondly adding concentrate to knapsack sprayers involves measuring relatively small quantities of the herbicide concentrate and then cleaning all measuring equipment. Finally the operator may be exposed to concentrated chemical when mixing and measuring, and diluted chemical in the form of spray mist during application. Many knapsack sprayers have no method by which nozzle pressure can be regulated easily and therefore a wide variation in the size of droplets produced can occur, giving the opportunity for drift onto the operator and non-target areas.

These factors have led to an increasing reluctance on the part of many operators to use conventional equipment and has provided the spur to develop better methods of handling and applying herbicides through knapsack sprayers. The objective of the Transformer Spraying System was to produce a portable sprayer which utilised conventional formulations, packaged and handled in such a way that the operator would not come into contact with the herbicide concentrate. To achieve this a novel packaging and handling system has been developed.

DESCRIPTION OF THE SPRAYING SYSTEM

The packaging system for the System utilises collapsible polyethylene bottles which will part collapse under gravity and collapse completely under low negative pressure. These packs are supplied part-filled with herbicide, and for use water is added directly to the bottles which are then connected to a dedicated sprayer.

The carton design of the Transformer herbicides allows the purpose built bottles to be filled in situ with a very high level of convenience. The Transformer sprayer consists of four main components all of which have been selected for their suitability for the application of viscous flowable herbicides. The complete system weighs only 8kg when fully loaded and allows treatment of up to approximately 1100m^2 from one bottle.

The Frame

The design of the frame is critical in that it forms the basis for the mounting for the pump and must be strong enough to withstand operation for in excess of 250 hours. The frame has been designed and constructed to allow the connection of the herbicide bottle in a rapid and leak-proof way. It has been manufactured to provide a strong, rigid, light and ergonomically comfortable unit, formed by the injection moulding of polyethylene. The pump selected is a novel positive displacement piston type which allows pressurisation of highly viscous fluids with low effort. The pump is manufactured from kemetal and withstands all commonly available herbicides of both flowable and suspension concentrate formulations. The pump is connected to a pressure equaliser to reduce pulsation. For accuracy, comfort and convenience hand lances need to be lightweight and to incorporate a positive on-off switch, and a pressure regulator. The hand lance utilised on the Transformer Sprayer incorporates these features, the benefits of which are that once the pressure is set excess pumping will not effect the nozzle pressure and output. The operator can change pressure (and therefore output) whilst on the move and the hand lance is designed to be suitable for spot treatments.

The Nozzle System

The Delavan DLD nozzles have been specially developed for use in the Transformer Spraying System. They allow the application of viscous flowable herbicides at an application rate of 45 l/ha. Tests on a paternator show good droplet distribution across a 1 m swath. These nozzles have a twin orifice system, which enables application at very low volumes with high accuracy across a 1 m swath. Conventional anvil nozzles produce a spray pattern with an unacceptable deposit on the swath margin. In addition swath width may be severely diminished at low volumes.

The Delavan DLD nozzles selected for use with the Transformer Sprayer exhibit a narrow droplet size spectrum with a relatively coarse spray quality. Tests have demonstrated that the Transformer Sprayer operating at a spray volume of 45 l/ha produces droplets with a volume median diameter of 610 μm compared to 454 μm for a Cooper Pegler CP3 with a Polyjet yellow nozzle operating at 164 l/ha. This results in the percentage spray volume accounted for by droplets of less than 100 μm being 0.1% and 0.9% respectively for the two systems. This reduction in the number and volume of small, drift prone droplets significantly reduces the possibility of operator and non-target area contamination.

Product dilution

The herbicides have been developed so that only one application rate is recommended. For the operator this involves topping up the herbicide bottle with the correct amount of water, thus errors in product dilution are virtually eliminated.

Pressure regulation

To achieve the target output at a forward walking speed of 1 m per second the pressure regulator is set at 1.5 bars. Therefore it is only if deviation from this walking speed is required that changes to the pressure need be contemplated. Calibration of the sprayer is achieved by measuring the quantity of chemical discharged over time and adjusting the pressure so as to obtain the desired output.

OPERATOR SAFETY

The Sprayer combines several features which improve operator safety compared to conventional sprayers. The effect of which is to eliminate almost completely exposure to concentrate by the addition of water to the container rather than vice versa. Secondly the coarse spray quality and the absence of a large percentage of fine droplets reduces significantly the drift potential from the DLD nozzles.

FIELD DEVELOPMENT

Materials and methods

During 1988 and 1989 trials were undertaken to compare the efficacy of herbicide applications made with The Transformer Spraying System and a conventional knapsack sprayer. The trials were located on soil types ranging from sandy loam to silty clay. All sites were initiated on non-crop land containing deep rooted perennial grass and broad-leaved weeds. Details of weed growth stages and populations at application are presented in table 1. There was no previous history of chemical use at any site.

Applications were made using a Cooper Pegler CP3 Knapsack Sprayer at 300 l/ha with a Lurmark 2.5AN anvil nozzle, and the Transformer Sprayer System at 45 l/ha with a Delavan DLD 0.5 HF nozzle. Trial design was related to land availability and the distribution of weed species at individual sites, and were of a randomised block or randomised strip design. The plot size was 1 x 4m with a 1m guard between plots replicated three times.

The herbicides applied were terbuthylazine/glyphosate (420/140 g a.i./l) at 2100/700 g a.i./ha and simazine/amitrole (300/180 g a.i./l) at 5400 + 3240 g a.i./ha.

Weed control was assessed visually using a 0-100% scale by comparison to untreated plots at 28 days after application and again between 56 and 84 days after application. Trials initiated in 1988 were also assessed for weed regrowth in the spring of 1989.

TABLE 1. Plant size and population at application

Weed	No. of Sites	No. of plants/m^2 From	To	Height (cm) From	To
Arrhenatherum elatius False oatgrass	1	7	13	5	35
Bromus mollis Soft brome	1	5	10	5	12
Cynosurus cristatus Crested dog's-tail	1	20	80	35	45
Dactylis glomerata Cocksfoot	1	0	50	30	95
Festuca rubra Red fescue	1	100	200	10	35
Convolvulus arvensis Field bindweed	1	10	30	10	20
Cirsium arvense Creeping thistle	1	3	5	19	30
Equisetum arvense Horsetail	1	30	100	15	25
Heracleum sphondylium Hogweed	1	0	3	15	25
Lactuca serriola Prickly lettuce	1	5	50	1	3
Mentha arvensis Corn mint	1	5	8	20	25
Plantago major Greater plantain	1	5	29	6	10
Ranunculus repens Creeping buttercup	1	10	50	3	10
Sonchus arvensis Perennial sowthistle	2	4	12	5	45

RESULTS AND DISCUSSION

There was no significant difference in weed control following applications using either spray system (Table 2).

Five grass weed species and nine broadleaved weed species were present at the time of application (Table 1). Of the grass species *Bromus mollis* (Soft brome), *Cynosurus cristatus* (Crested dog's-tail), *Dactylis glomerata* (Cocksfoot) and *Festuca rubra* (Red fescue) were all fully controlled. *Arrhenatherum elatius* (False oatgrass) was suppressed by terbuthylazine/glyphosate. For the broadleaved species *Lactuca serriola* (Pickly lettuce), *Ranunculus repens* (Creeping buttercup) and *Sonchus arvense* (Perennial sowthistle) were all fully controlled by both herbicides, *Equisetum arvense*, (Horsetail) was effectively suppressed. *Convolvulus arvensis* (Field bindweed), *Cirsium arvense* (Creeping thistle) and *Heracleum sphondylion* (Hogweed) were moderately suppressed by terbuthylazine/glyphosate, complete control of *Mentha arvensis* (Corn mint) and *Plantago major* (Greater plantain) being obtained.

Terbuthylazine/glyphosate at the rate used is not recommended for the control of several of the species encountered (a higher rate being required in these cases). The lower rate was used in order to compare growth suppression by the herbicide from the two application methods and in all three cases (C. arvensis, C. arvense, and H. sphondylium) there was no significant difference in control.

The accuracy of application was superior with the Transformer sprayer to that with the knapsack. The Transformer Sprayer gave a clearly defined lm swath width, with no drift into the guard plots. In contrast the applications from the knapsack sprayer had contaminated the guard plots with plants up to 1 m away affected. This effect was most marked four weeks after application where knapsack applications were showing greater weed control at the plot margin with relatively poor control at the center of the plots. Later assessment however, demonstrated greater uniformity of control although still inferior in this respect in comparison to the Transformer Sprayer applications.

All the 1988 season applications were assessed for weed regrowth during the spring of 1989. No significant differences in control from the two application methods were noticed with most species being fully controlled. The difference in the uniformity of control between the two application methods noted in 1988 was no longer apparent presumably due to movement within the soil of the residual herbicides.

TABLE 2. Control of annual and perennial weeds with terbuthylazine/glyphosate (2100/700 g a.i./ha) and simazine/amitrole (5400 + 3240 g a.i./ha) through conventional and Transformer systems.

Treatment		Simazine/ amitrole		terbuthylazine/ glyphosate	
Application Method		*C	*T	*C	*T
Weed species		mean % control 56 - 84 daa			
	No.Sites				
Arrhenatherum elatius	1	-	-	85	85
Bromus mollis	1	100	100	100	100
Cynosurus cristatus	1	100	100	100	100
Dactylis glomerata	1	99	100	100	100
Festuca rubra	1	100	100	100	100
Convolvulus arvensis	1	-	-	50	43
Cirsium arvense	1	-	-	45	40
Equisetum arvense	1	88	88	87	83
Heracleum sphondylium	1	-	-	65	66
Lactuca serriola	1	98	99	97	100
Mentha arvensis	1	-	-	100	100
Plantago major	1	-	-	100	100
Ranunculus repens	1	100	99	100	100
Sonchus arvensis	2	100	100	100	100

*C = Cooper Pegler, *T = Transformer

These studies have demonstrated that there is no loss in efficacy from application of these herbicides at the rates used through the Transformer Spraying System. As the herbicide formulations employed in these studies have both contact and residual activity it is expected that other herbicides, irrespective of the mechanism of action, would perform satisfactorily when applied via the Transformer Spraying System.

The very high dose rates of simazine/amitrole (18 litres of formulated product/ha) at low volumes (45 l/ha) demonstrated that very viscous solutions can be applied through the Transformer spraying system with a Delavan DLD nozzle with no loss in residual or contact activity.

CONCLUSION

The System provides a lightweight and convenient method of application whereby errors in product dilution and application are minimised. It enables accurate placement of spray and high levels of weed control using conventional formulations with increased work rates, very low risk of operator contamination and minimal drift to non-target areas.

ACKNOWLEDGEMENTS

The authors wish to thank Mr J Burgess for his assistance and co-operators for providing trial sites.

TOWARDS DRIFT-FREE SPRAYING

N. DOMBROWSKI, I. HIBBITT, J.R. STRACHAN

Department of Chemical Engineering, University of Leeds, Leeds LS2 9JT

ABSTRACT

Agricultural hydraulic spray nozzles produce large numbers of very fine droplets that are susceptible to drift. This results from the mechanism by which the liquid sheets, emerging from the orifices, break down. The properties of the gaseous environment have a significant effect on the processes of sheet disintegration and resulting drop-size spectrum. It was discovered in the Department of Chemical Engineering (Leeds University) that a hot atmosphere causes enhanced breakdown which is accompanied by a reduction of at least 90% of the small particle content and hence the drift potential.

These findings have been utilised in the development of a Hot Gas Applicator (H.G.A) and a prototype 7m crop sprayer has been constructed incorporating a number of nozzle/H.G.A assemblies. Initial field trials indicate effective drift-free operation and constancy of spray angle over a range of wind speeds and nozzle pressures. Computer modelling has been used for predicting the effect of nozzle height and spacing on spray patterns below the boom.

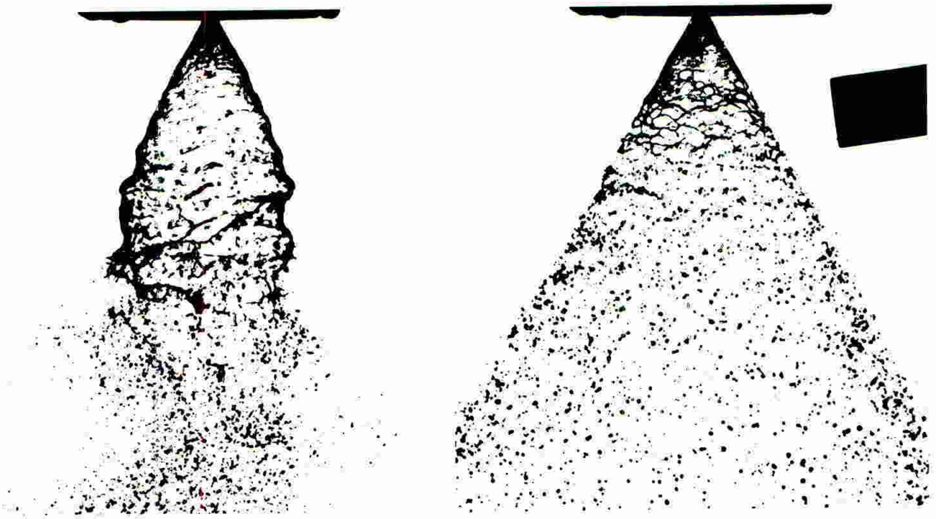
INTRODUCTION

It is now universally acknowledged that spray drift is an undesirable feature of agricultural spraying techniques generally in use and its reduction therefore, is an urgent priority.

Drift results from the suspension in the air of very fine droplets which are produced in very large numbers from conventional agricultural hydraulic fan and cone spray nozzles. The reason for this is indicated in Fig. 1 (LHS) which shows the processes of drop formation from a cone (or swirl spray) nozzle. The liquid is caused to emerge from the nozzle orifice in the form of a thinning sheet which interacts with the surrounding air to form unstable sinuous waves. Each wave amplitude increases with distance from the orifice until the crests become so thin that they burst forming clouds of fine droplets. It was reported earlier (Dombrowski, 1975, 1984) that this mechanism can be changed by passing the sheet through a hot gas atmosphere whereby wave growth is inhibited and the sheet rapidly disintegrates into a network of threads (see Fig. 1 RHS), which subsequently break down into a narrower drop-size range with a significant reduction of the small particle content.

The important implications of this discovery to agricultural spraying was recognised by the Ministry of Agriculture Food & Fisheries, and a research and development programme was sponsored at Leeds University to

Fig.1 Effect of hot gas on processes of drop formation.



design a hot gas applicator (H.G.A) incorporating a miniature propane burner, which could be simply fitted to a crop sprayer. This has been achieved, and a prototype 7m crop sprayer has been constructed incorporating a number of nozzle/H.G.A assemblies. The purpose of this paper is to report on some preliminary studies of the drop-size characteristics and predictions of spray deposition patterns below the boom.

EXPERIMENTAL

Drop sizing

Accurate drop sizing of sprays, in the presence of hot gases is difficult to achieve. Spark photography would appear to hold out the most promise since the narrow spray annulus, existing under hot gas conditions should obviate depth of field problems. However, image analysis without access to automatic means is a tedious task. Laser scattering systems overcome this problem but the performance is seriously affected by refracture index gradients if the laser beam passes through the hot gas. However this system was selected because of the rapidity with which measurements can be made, and because advantage could be taken of the fact that in still air natural air entrainment from the surrounding atmosphere causes the hot gas to be drawn down along the spray axis. Hence by ensuring that the laser beam is located sufficiently off-axis interference by the hot stream may be avoided. However, small droplets follow the same path towards the axis with the consequence that many of them will not be recorded. However this was not considered a serious disadvantage since the extent of the reduction of the finer droplets under hot gas conditions is visually evident, and the main objective of these experiments was to determine the size characteristics of the bulk of the spray. A Malvern Instrument 2600 drop-sizer was employed with the 600 mm lens, the only available focal length, using the company's Model Independent Program.

When examining the results it should be noted that the data is presented in fifteen size bands only with particularly large bands employed for the large drop sizes. This will tend to considerably over-estimate the mass concentration in the last two or three bands. Reduced, although still large errors, would have been introduced with the 1000 mm lens. The first phase of the work has encompassed a range of differential pressures from 1 to 2.4 bar. The laser beam was located at the same position for both 'cold' and 'hot' sprays.

Spray Deposition

Apart from excessive drift, hollow cone spray nozzles have generally been considered to be unsuitable for crop spraying on account of their double-peaked spray patterns (Van der Weij, 1970), which vary with boom height (Nordby 1970) and wind speed. However, the change in the mechanism of sheet disintegration arising from the application of a hot gas stream also brings about a significant change in the spray geometry with the spray concentrated in a narrow annulus following a well-defined path, little affected by wind or tractor speed, or boom height.

A preliminary investigation into the spray deposition characteristics has therefore been undertaken. This has taken the form of patternating the spray diagonally across the spray annulus and using the results to predict the lateral deposition along the boom as a function of boom height and nozzle spacing. Because of the general finding of liquid maldistribution around the nozzle axis, for most of the nozzles used, measurements were made at three angular positions and the results averaged. The patternator consisted of a line of 1.2 cm square-sectioned tubes located 50 cm below the nozzles.

Nozzles

Hollow-cone nozzles were obtained from a number of manufacturers to cover a flow range of 0.36 to 1.22 l/min (at 2.4 bar) and spray cone angles from 60-90°.

One specimen only of each type of nozzle was examined, except when there were obvious manufacturing faults, and the results cannot therefore be considered to be necessarily representative of the manufacturers' standards. The nozzles are therefore not being identified at this stage and are referred to by a code letter.

RESULTS

Drop-Size Spectra

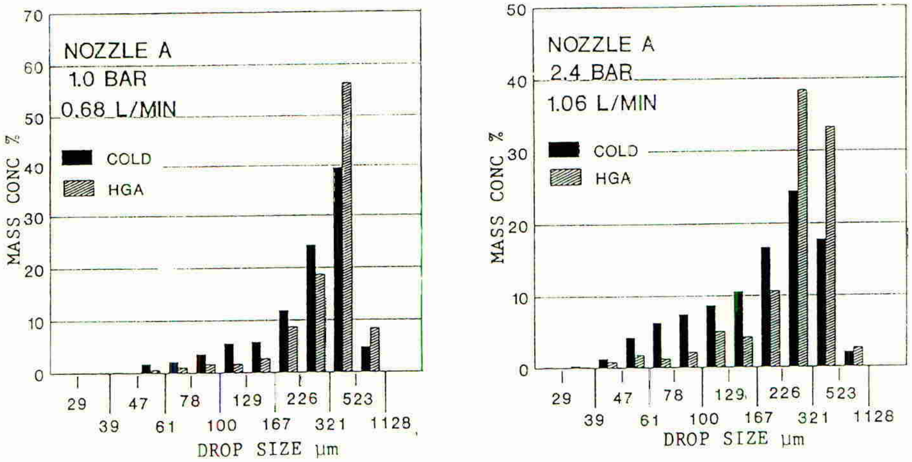
Some of the results are presented in the form of histograms (Fig. 2) and the remainder summarised in Table 1, where the bracketed data correspond to results for normal (cold) conditions. It will also be noted that application of hot gas causes a small increase in the spray sheet angle.

Fig. 2 shows the effect on drop-size of hot gas for nozzle A at two pressures. The results show, particularly at the highest pressure of 2.4 bar, a marked narrowing of the spectrum caused by a significant reduction of the mass concentration of the smaller particles. Reference to Table 1 shows

TABLE 1 Spray characteristics of nozzles tested

Nozzle	Pressure (bar)	Flowrate (l/m)	Sheet Angle°	% mass in size bands (μm)			
				100-321	169-321	321-523	532-1128
A	2.4	1.06	81(76)	58(60)	49(41)	33(18)	3(2)
	1	0.68	"	32(34)	27(36)	56(40)	8(5)
B	2.4	0.58	79(78)	68(62)	52(30)	14(4)	2(0.1)
C	2.4	1.22	61(59)	43(48)	36(36)	45(38)	8(4)
D	2.4	1.21	74(71)	39(42)	33(37)	53(37)	5(5)
E	2.4	0.72	68(66)	71(63)	59(38)	19(7)	1(2)
F	2.4	0.72	87(86)	75(64)	59(35)	13(4)	0.5(0.1)
G	2.4	1.14	71(69)	32(55)	27(40)	48(31)	16(2)

Fig. 2 Effect of hot gas and pressure on drop-size spectra.



no change in the 100-321 μm size band, a slight increase in the 169-321 band with greater increases in the larger bands although, as mentioned above, caution should be exercised in accepting the absolute figures. At lower pressures there is a progressive coarsening of the spray.

The effect of flow rate under H.G.A conditions is demonstrated for nozzles A and B at a pressure of 2.4 bar. Reduction of flow rate causes an increase in the 100-321 μm size band, and a reduction of mass in the higher size bands.

The range of nozzles employed allowed an evaluation of the effect of angle at two levels of flow, viz, 0.72 l/min for nozzles E and F and 1.22

l/min for nozzles C and D. Both sets of data indicate little effect of angle on the drop size of the bulk of the spray.

A comparison was also made of different proprietary nozzles and it was found that certain nozzles produce coarser sprays (see, for example, nozzles D & G). No attempt at this stage was made to ascertain whether this was due to nozzle design and/or manufacturing errors.

Spray Deposition

Typical results for water distribution across the spray annuli are shown in Fig. 3 for nozzle A over a range of pressures. Deposition characteristics depend upon the extent to which adjacent spray annuli overlap each other. The latter depends upon the nozzle spacing and nozzle height. Fig. 4 presents predicted values of the coefficient of variation (cv) for nozzle A operating at 2.8 bar with two nozzle spacings over a range of boom heights. As expected, (Mawer, 1988) improved coverage is achieved at larger heights and in this respect it should be noted that with the reduction of drift potential achieved with the H.G.A system, spray operation at higher boom levels is now a practical possibility.

The figure also demonstrates that cv's of about 12% should be achievable at moderate boom heights, the minimum height diminishing with reduction of the spacing.

Fig. 3 Radial water distribution across annuli.

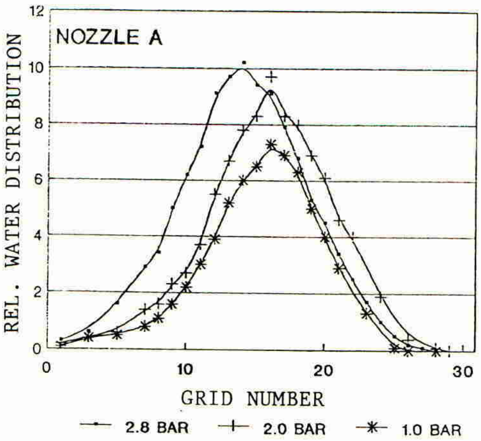
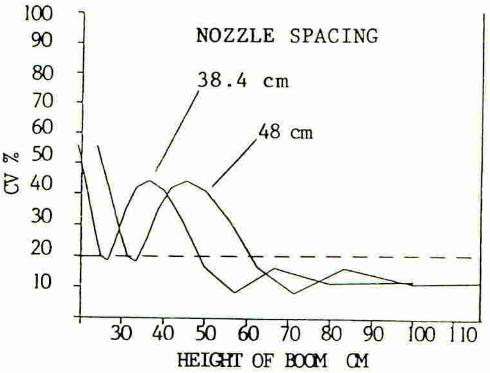


Fig. 4 Variation of cv with nozzle spacing and boom height.



CONCLUSIONS

The results of this preliminary study indicate the potential for effective drift-free spraying with acceptable lateral spray distribution along the spray booms. However, a more extensive experimental study needs to be made over a wider range of conditions, e.g. pressures, nozzle sizes, spray angles, and to carry out biological tests. It is also necessary to carry out a comparative study of the performance characteristics of hollow-cone nozzles produced by different manufacturers.

It was also previously pointed out (Dombrowski 1984) that since break-down of the sheet now takes place very close to the nozzle, important implications for spray nozzle operation now arise. Normally, if a nozzle is used below its minimum designed working pressure, surface tension causes the sheet to be drawn inwards towards the axis and the resulting spray is directed along a relatively narrow angle (Fig. 1 LHS). When hot gas is introduced, break-down occurs in the upper region of the cone where the angle of divergence is at or near its maximum, and the spray consequently issues at a larger angle (Fig. 1 RHS) This phenomenon results in the spray angle becoming effectively independent of pressure, the lowest practical value being limited by the setting of the anti-drip valve. Table 1 (Nozzle A results) shows a marked coarsening of the spray with reductions of pressure, but this is of no consequence in applications, e.g. in Autumn, where ground coverage only is required. Since the spray coarsening is accompanied by a further reduction in the mass of the finer droplets the system would permit the use of relatively low water flow rates albeit at higher chemical concentrations, without the usual accompanying disadvantage of more toxic spray drift.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the contributions to the development of the crop sprayer of C F Hockenhull, R Holt, Dr A D Quigley and the late A A M Brash. The drop-size and deposition data were abstracted from student project work carried out by W J Boucher, J Cavanagh, M J Curwen, K Day, M B Hawtin and R Sunderland. They also wish to thank Dr E A Foumeny for his advice on computational modelling, and MAFF for the provision of a research grant.

REFERENCES

Dombrowski, N. (1978) British Crop Protection Council. Monograph No.22 - Controlled Drop Application. Informal contribution, referred to by Gunn, p.1.

Dombrowski, N. (1984) Reduction of drift in agricultural sprays. Laboratory News, 16 Nov. 1984. p.6.

Mawer, C J. (1988) The effect of nozzle characteristics and boom attitude on the volume distribution below a boom. AFRC Engineering Research, Divisional Note DN 1462.

Nordby, A. (1970) British Crop Protection Council Monograph No.2 - Symposium for Research Workers on Pesticide Application 1970, pp. 12.22.

Van der Weij, H.G. (1970) ibid pp. 12-20.

A COMPARISON OF SPRAY DRIFT COLLECTION TECHNIQUES

P C H MILLER, P J WALKLATE, C J MAWER

AFRC Institute of Engineering Research, Process Engineering Division, Wrest Park, Silsoe, Bedford, MK45 4HS

ABSTRACT

A series of field experiments examined the comparative performance of difference types of spray drift collector surface including 2 mm diameter vertical lines and a number of discrete collector types.

Wind tunnel experiments also measured the spray drift collected with different surface types operating in a range of wind speeds and spraying conditions. These experiments used a laser imaging droplet size analyser in addition to the capturing surfaces so as to measure the droplet size, velocity and volume flux in the sampling region. Computer simulation techniques have been used to interpret the consequences of these studies.

Results show that although existing relationships give some indication of collector performance, local conditions also affect the way in which drift is collected. It is concluded that the passive drift collectors used in this study, should not be used in local wind speeds of less than 2 m/s.

INTRODUCTION

In Europe the control of spray drift is becoming an important aspect of sprayer performance assessment particularly with respect to environmental and non-target organism contamination. Field and laboratory assessments of spray drift have been made with a range of collector surfaces and geometrical arrangements. (Parkin and Merritt, 1988).

The relationship between collection efficiency, droplet size distribution, wind speed and the characteristic dimension of the collector has been defined for a number of collector types (May and Clifford, 1967) but in many field and laboratory drift studies these conditions are not known at the collector mainly due to droplet evaporation. In addition to this, wind velocity variations (spatial and temporal) can bias the effectiveness of the collector.

Many drift studies have not attempted to relate measured drift volumes to absolute estimations of airborne spray because of the difficulties of estimating collector efficiencies in the field but have compared different spraying treatment. However, such 'comparative' studies inherently neglect any biasing effects of the drift collector.

The development of computer simulation techniques to predict spray transport and laser based instrumentation to measure droplet size and velocity distributions have provided the basis for examining the performance of different collection systems. The work reported in this paper used wind tunnel and field experiments to compare spray drift collector performance. Computer simulation studies have also been used to indicate the likely sampling conditions for different spraying operations and to predict the effect of capture efficiency on measured spray drift volumes.

WIND TUNNEL EXPERIMENTS

A Particle Measuring Systems optical imaging probe (Type 2D-GA1) was mounted in the wind tunnel at AFRC Engineering which has a working section of 2 m wide and 1.5 m high and is 7.6 m long. This was used to monitor airborne spray volumetric flux down-wind of a single flat fan spray nozzle which was traversed at a speed of 0.75 m/s normal to the airflow. Surface type collectors in common use for drift measurement were positioned (in an array) either side of the probe and these included 2 mm diameter polythene tubing and pipe cleaners (nominally sampling over a 6.8 cm length), hair curlers (as used by ICAP at Cranfield) and a rotorod fitted with 3.5 mm diameter sampling straws. The spray liquid was a 0.1% solution of sodium fluorescein with 0.1% of a surfactant and deposits on the collector surfaces were determined by fluorimetry. The surface collectors were replicated within the array and were placed in different randomised orders so as to minimise any effects due to air flow patterns within the tunnel. A total of four sets of runs were completed giving a range of airborne spray concentrations and wind speeds at the collectors as follows:

Set 1. Using a F110/1.6/3.0 nozzle mounted 0.5 m above a false floor in the tunnel with an opening to simulate the effects of a crop canopy and to minimise the effects of splash and recirculation of the spray close to the tunnel floor. Collectors were mounted 1.0 m down-wind of the nozzle track and 0.2 m above the false floor. Air flow conditions were controlled to give a uniform mean velocity of 3.0 m/s at the spray nozzle with a low level of turbulence (no velocity profiling baffles were used at the tunnel inlet).

Set 2. Using a F110/0.4/3/0 nozzle mounted 0.5 m above an absorbent floor surface. Collectors were mounted 2.0 m down-wind of the nozzle track and 0.375 m above the floor. An air velocity of 2.0 m/s at the nozzle was used with an approximately logarithmic velocity profile produced by upstream baffles (Mawer et al, 1989) which also induced considerable turbulence.

Set 3. As for Set 2, but with a mean wind speed of 2.6 m/s at the nozzle and no velocity profiling baffles usptream - i.e. a lower level of turbulence as used in Set 1.

Set 4. As for Set 3, but with the collectors raised to 0.4 m above the floor.

Results from these runs are summarised in Table 1 and the measured droplet size distributions of the drifting spray for Sets 1 and 4 are shown in Fig.1.

TABLE 1. Comparative collected drift volume fluxes in wind tunnel experiments

Set Number	Collected Drift, $\mu l/cm^2/pass$ 2mm Tube	Curler	Pipe Cleaner	Rotorod	PMS
1	1.39	2.18	2.53	0.045	6.57
2	0.032	0.032	0.155	0.053	0.227
3	0.112	0.065	0.083	0.077	0.123
4	0.017	0.035	0.044	0.031	0.076

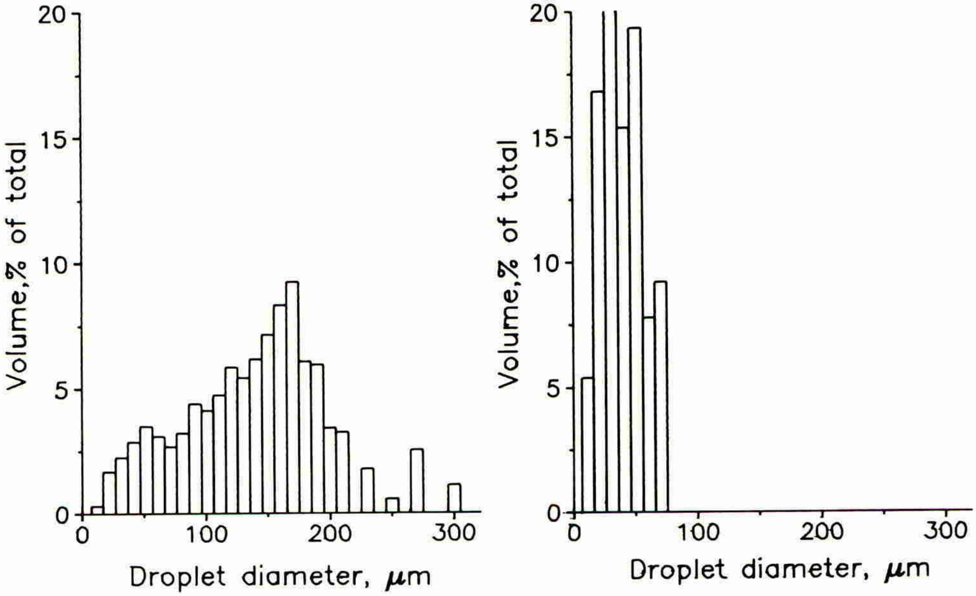


Fig.1. Droplet size distributions of drifting spray for sets 1 (left) and 4(right)

The effective collection areas for each of the systems was based on the measured nominal dimensions of the collectors. The laser on the PMS was assumed to have an effective area of 650 µm diameter x 44 mm long and for the rotorod the effective area was calculated by assuming that the projected rotating diameter was completely sampled at a wind speed of 0.45 m/s and was reduced pro-rata at higher wind speeds. It is accepted that this estimation of area particularly for the rotorod and the pipe cleaner is a crude approximation since the true sampling area is very difficult to define.

The experimental conditions were selected to give drifting spray clouds of reducing density with set numbers and this is reflected consistently in the results from the Particle Measuring System probe and the pipe cleaner collectors. Set 1 corresponded to a very high airborne spray concentration down-wind and only 6 double passes of the nozzle were used to build up measurable spray deposits over a period of approximately 30 seconds. Under these conditions, the rotorod which was designed to sample very low airborne concentrations was over-saturated and under-estimates the drift volume flux. In Sets 2-4, 20 double passes of the nozzle were used over a period of approximately 90 seconds.

All surface collection systems gave lower volume fluxes than the Particle Measuring System probe as expected.

The droplet size measurements for the drifting spray gave volume median diameters of 144, 75.1, 36.8 and 38.0 µm for Sets 1 to 4 respectively with percentage volumes in droplets less than 100 µm of 28.2, 83.7, 98.5 and 100% respectively.

There was some variability and inconsistency in the measured drift deposits and this may have resulted from the turbulent effects of moving the nozzle across the air flow in the tunnel and these effects could be seen during the experiment.

FIELD EXPERIMENTS

These were conducted in two conditions as summarised in Table 2 using both boom and air-assisted orchard sprayers.

TABLE 2. Field experimental conditions

Experiment	Surface conditions and sprayer type	Mean wind speed at 2m, m/s	Relative humidity, %	Ambient temperature, °C	Richardson number at 4m
1 (a)	Grass surface approx 150 mm tall Boom sprayer	3.19	49	26.1	-0.09
1 (b)	As above Orchard sprayer	1.89	47	26.7	-0.06
2	Bare soil surface Boom sprayer	6.70	84	3.7	-0.01

Drift was measured using 2 mm plastic tubing, pipe cleaners, hair curlers and microscope slides. The discrete collectors were supported at 0.5 m intervals from masts 3.5 m tall and the plastic tubing was sampled in 0.5 lengths. In run 1(a) the 12 m boom sprayer was operated at a nominal foward speed of 8 km/h spraying with F110/1.6/3.0 nozzles at a spacing of 0.5 m on the boom and 0.5 m above the top of the crop. The spray solution was sodium fluorescein with 0.1% of a surfactant and spray deposits were determined by fluorimetry. Run 2 used an 18 m air-assisted sprayer fitted with F110/0.67/2.5 nozzles but operated without the air-assitance. The boom height was 1.1 m, spraying sodium fluorescein and a surfactant with drift deposit determined by fluorimetry. In run 1(b), the orchard sprayer was operated at a forward speed of 6.5 km/h and was fitted with a full arc of HC/1.7/7.0 nozzles spraying a 0.1% solution of a tracer dye (orange G - BDH Ltd). Spray drift deposits were determined by spectrophotometry.

Measured spray drift profiles for the boom sprayer runs are plotted in Fig.2 and for the orchard sprayer in Fig.3. In all experiments the general form of the measured drift profile was similar with each of the collectors used. In Fig.2 (right) the performance of the pipe cleaner with respect to both the 2 mm line and the slide were in general agreement with the wind tunnel results. The difference between the line and pipe cleaner collectors tended to reduce with increasing height possibly due to the effects of the increasing wind velocity which increases collector efficiency. At the lower wind speed (Fig.2 left) there was little difference between the drift values obtained with the curler and pipe cleaners and absolute values were much lower than exp.1a. When sprayed with the orchard sprayer (Fig.3), pipe cleaners indicated higher drift values than the curlers so agreeing with the laboratory experiments but both were lower than the values from the line collector which was not expected. One possible explanation for these results is that in the conditions down-wind of an orchard sprayer, the line collectors effectively collected drift on backward facing surfaces in addition to those directly facing the wind direction due to small scale turbulence.

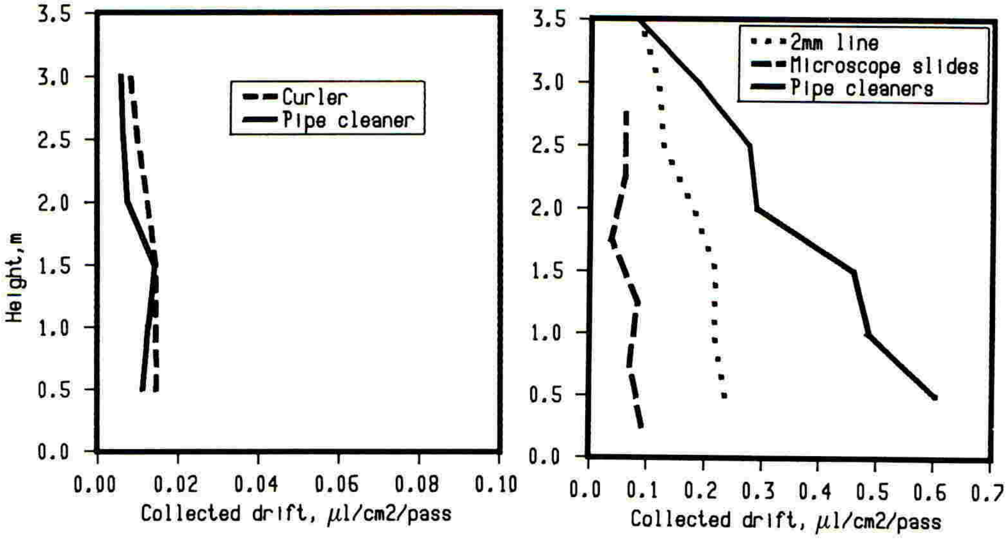


Fig.2. Spray drift from a boom sprayer over grass (left and bare soil (right) surfaces

In addition to the use of surface collectors for assessing horizontal fluxes, measurements were also made at ground level using microscope slides and metal pins. The results are summarised in Table 3.

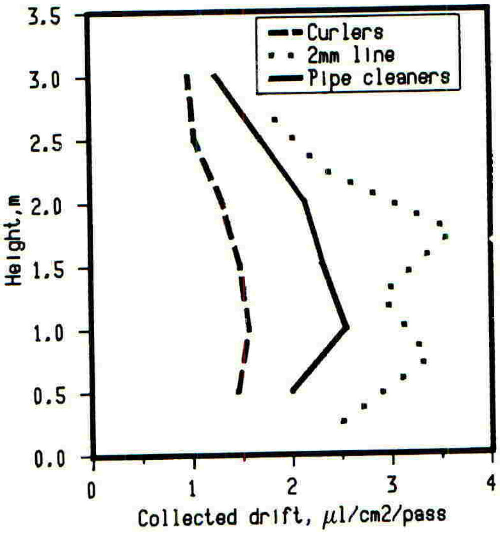


Fig.3. Spray drift from an orchard sprayer

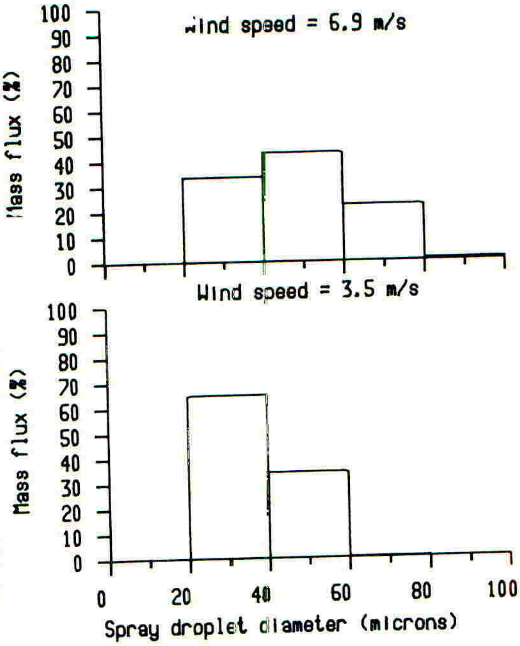


Fig.4. Predicted droplet size distributions of airborne spray at different wind speeds

TABLE 3. Measured drift volumes µl/cm2/pass at ground level.

Experiment	Collector	Distance down-wind, m 0	 8	 20
1 (a)	Slide	0.017	0.00012	0.00007
	Metal pin	0.058	0.0011	0.0012
1 (b)	Slide	0.79	0.49	0.19
	Metal pin	1.47	1.05	0.51
2	Slide	0.060	0.0098	0.0035

COMPUTER SIMULATION MODELS

Existing simulation models (Miller and Hadfield, 1989; Walklate 1987) can be used to predict the droplet size distribution at spray drift collectors for a range of spraying conditions. Fig.4 shows the predicted size distribution of airborne spray 8 m down-wind of a 12 m sprayer operating with F100/1.6/3.0 nozzles in a range of wind speeds of up to 7.0 m/s measured at a height of 2.0 m. In these conditions all of the drifting spray is calculated to be in droplets less than 100 µm in diameter, and this confirms results from previous drift studies (Miller, 1988).

Computer models can also be used to study the effects of different collector efficiences based on defined relationships (May and Clifford, 1967). Fig.5 shows the predicted down-wind line deposits as a fraction of those measured at 8 m when spraying in an orchard with an air-blast sprayer fitted with HC/1.7/7.0. These results show that at distances of 20 m down-wind and greater, very large discrepancies in measured drift values can be introduced by using static line collectors. For a typical orchard drift simulation with a force 2 wind, a 0.6 mm diameter line 10 m high collects 3 times as much drift as a 2.0 mm line. The increased collection efficiency can mean that no loss of resolution is sacrificed by using the smaller collector. Preliminary field experiments to date support the results of these simulation studies.

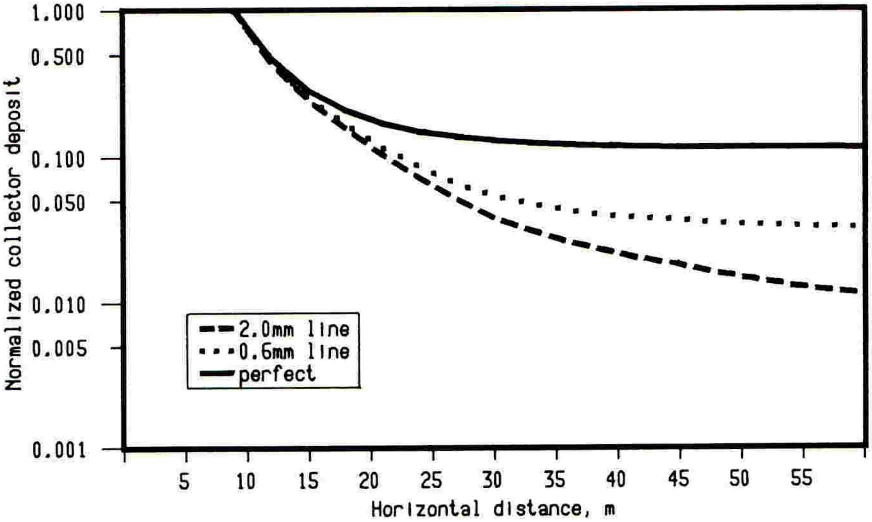


Fig.5. Predicted drift deposits as a fraction of those at 8 m for different collector efficiencies

DISCUSSION

One of the major difficulties in comparing drift measured by the different collectors is to relate the effective collecting areas of capture. This is particularly difficult where the collecting surface is not well defined as in the case of the pipe cleaners because of the nature of the hairy surface and with the rotorod because it changes the local air flow. Many drift experiments express results in terms of the spray emission at the nozzle and hence need to estimate total spray drift from the collector deposits. Results from this study have shown that such projections can give variable results even if some corrections are made to account for different collection efficiencies based on published relationships (May and Clifford, 1967).

In comparing measured drift values from the different collection surfaces, differences may relate to the different sampling areas of the systems particularly if there are steep gradients in the airborne spray concentrations in the region of the sampling devices. In the wind tunnel where perhaps such gradients are more likely, attention was given to matching sampling areas where possible. For example, in Sets 3 and 4 the PMS laser was used vertically as were the pipe cleaners, strings and curlers so as to match the geometry of the rotorod as closely as possible.

Results from the computer modelling studies show that drift beyond 8 m down-wind particularly from boom type sprayers is mainly in droplets with a diameter of less than 100 µm. For this reason it is important that collectors with relatively high capture efficiences are used and that results from experiments in low wind speeds (less than 2 m/s at the collector) are treated with great suspicion in particular for the purpose of extrapolating data to different wind speeds. Drift collectors mounted close to the ground in field experiments are likely to see only low wind velocities because of velocity profile effects and hence have a poor captive efficiency.

In considering the adoption of techniques for drift assessment under both field and laboratory conditions, it must be recognised that collection efficiences will commonly be in the order of 50% or less. Absolute estimates of total spray drift volumes will continue to be difficult to obtain particularly when under field conditions.

The use of wind tunnel and computer simulation techniques offer the possibility of developing standard protocols for examining the "driftability" of spraying systems but further work is required to derive suitable test methods. There will continue to be a need for field experiments both to verify other approaches and to obtain data that cannot be successfully modelled.

ACKNOWLEDGEMENTS

Particular thanks are due to Dr C R Merritt and Mr W Taylor for their contribution to initiating this work and their help with the experiments. Dr Merritt assisted with the wind tunnel experiments and Mr Taylor played a major role in setting up the field experiments and analysing the drift deposits on the collectors. Thanks are also due to members of Chemical Application Group at AFRC Engineering for their help with the work, particularly Mr C R Tuck and Dr P A Hobson.

REFERENCES

Mawer, C.J.; Miller, P.C.H.; Davis, P.F.; Gilbert, A.J.; Bell, G.J. (1989) Comparative spray drift studies from hydraulic nozzles. Submitted to Crop Protection.

May, K.R.; Clifford, R. (1967) The impaction of aerosol particles on cylinders, spheres, ribbons and discs. Annual Occupational Hygiene, **10**, 83-95.

Miller, P.C.H. (1988) Engineering aspects of spray drift control. Aspects of Applied Biology, **17**, 377-384.

Miller, P.C.H.; Hadfield, D.J. (1989). A simulation model of the spray drift from hydraulic nozzles. Journal of Agricultural Engineering Research, **42**, 135-147.

Parkin C.S.; Merritt, C.R. (1988) The measurement and prediction of spray drift. Aspects of Applied Biology, **17**, 351-362.

Walklate, P.J. (1987) A random-walk model for dispersion of heavy particles in turbulent air flow. Boundary-Layer Meteorol. **39**, 175-190.