2.
Environment, Health and Safety

Chairman: A. BIDE

SOME IMPLICATIONS OF RECENT SAFETY LEGISLATION FOR AIR-ASSISTED SPRAYING

TERRY FAULL
Health and Safety Executive, Daniel House, Trinity Road, Bootle L20 7HE

ABSTRACT

Recent legislation requires that reasonable precautions must be taken to protect people and the environment whenever pesticides are used. Some air-assisted sprayers create conditions which make it difficult to control off-site drift. Analysis of incident investigations confirms that a significant proportion arise from the use of such machines in orchards and hop gardens. Actions to reduce the risks are outlined and include separation distances, changes in operating procedures and advance warning of neighbours. Claims that systems which use air to carry droplets down into a crop make a significant improvement to safety when used as recommended by some manufacturers is challenged.

INTRODUCTION

Health and Safety sells very few spraying machines. Sprayer design has certainly been influenced by the need to control drift and protect the operator but features to achieve this have, until recently, been given little prominence in sales literature. The changes brought about by legislation including the Food and Environment Protection Act 1985 (FEPA), the Control of Pesticides Regulations 1986 (COPR) and the Control of Substances Hazardous to Health Regulations 1988 (COSHH) mean that pesticide users will now look to machine manufacturers to help them achieve the improvements needed to reduce hazards to the operator, the public and the environment.

This paper consider the implications of the legislation for the use of air assisted sprayers. This term is taken to include air-blast machines where high velocity air carries the spray into bushes and trees and also the more recent air assisted placement sprayers in which spray droplets are carried down into a crop wholly or partly by a flow of air.

THE LEGISLATION

All use of pesticides is now set within the context of responsibilities which pesticide users and their employers have under COPR and COSHH. Broadly these may be defined under 3 headings:

- Action to protect the operator
- Action to protect the public
- Action to protect the environment

In each case there is a need to act reasonably. While only the Courts can determine what was reasonable in particular circumstances, detailed guidance for spraying in agriculture and horticulture was published in May 1990 in the FEPA/COSHH Code of Practice: The Safe Use of Pesticides on Farms and Holdings.

PROBLEMS LINKED TO AIR ASSISTED SPRAYING

When applied to air assisted spraying the reasonable steps required by the legislation mean that particular attention must be given to the prevention or control of drift. A number of studies have shown that air assisted spraying of trees and bushes is inefficient and prone to drift (Morgan 1981; Elliott and Wilson 1983; Walklate 1988). While droplet drift from conventional hydraulic sprayers is seldom a serious problem at distances greater than 10 metres from spraying operations, an air-blast sprayer used for orchard work may deliver between 1% and 5% of the active ingredient beyond 20 metres. At low volume application rates up to 16% of the active ingredient may drift beyond this distance (Walklate 1988).

The significance of such levels of drift off-site will depend on the biological activity of the pesticide and the site of its deposition. In any analysis of the extent of the problem there are difficulties in identifying relevant data. Table 1 shows the acreage of orchard and hops treated in England and Wales:

TABLE 1. Annual treated area and pesticide usage (excluding herbicides)

	Area Treated (hectares)	Pesticide use (tonnes)
Orchards	581135	618.36
Hops	103363	106.38

It is not possible to confirm what proportion of the 684498 hectares were treated using air assisted equipment but, on the assumption that 100% of the pesticides were applied in this way, it represents an estimated 2.6% of the area of grassland, cereals and other arable crops treated annually. (Source: MAFF Pesticide Usage Survey Report 41).

One measure of the extent of problems from air-assisted sprayers is the number of such incidents investigated by HM Agricultural Inspectors (HMAI) of the Health and Safety Executive. Table 2 indicates that the occurrence of these cases is greater than the proportional usage of such machines would suggest:

TABLE 2. Percentage of air-assisted spraying of all incidents investigated by HMAI

	1987	1988	1989
Posioning incidents	7%	6%	11%
Complaints	10%	4%	18%

There is sufficient evidence to support a view that those who use air assisted sprayers must seek improvements in the way they apply pesticides.

Operator safety

Exposure to the pesticide concentrate is a potential hazard whatever spraying system is used. The first step in complying with the legislation is therefore to ensure that pesticides are applied only when necessary and that the least hazardous product consistent with an appropriate level of control is selected. Use of closed filling systems and devices such as induction bowls or probes should now be standard practice to reduce the risk of operator contamination during the initial stages of the operation.

At many times of the year orchard spraying with an air-blast machine is a wet, and uncomfortable job. Some orchards and hop gardens may restrict the driver to the use of a tractor without a protective cab; clothing then provides the only means of controlling exposure to the droplets, mist or vapour. For example an operator using mancozeb at a reduced volume rate would need to wear the following clothing where the COSHH assessment showed that it was not reasonably practicable to use a cab fitted with a suitable forced air filtration unit:

Coverall	Face-shield
Gloves	Hood
Boots	Filtering facepiece respirator

Use of clothing as the only means of operator protection is challenged by COSHH and will be increasingly difficult to justify. A change to machines which protect the operator by design and engineering means and also the use of non-hazardous means of pest control are ways which HMAI will expect to be increasingly adopted.

Protecting your neighbour

Members of the public seek to share in the agriculturalists' good fortune of having access to the countryside, they are also neighbours and customers. They must be considered when air assisted spraying is planned. Air-blast equipment with an effective swath width of 8 metres or more and which transports droplets into a 15 metres high canopy, has clear implications for anyone passing by or who is present on adjacent land.

Wind speed and direction must be determined accurately and when considered with information such as spray pressure and droplet size, may indicate a need to leave a buffer zone, to block off some nozzles, or reduce forward speed and spray pressure. There is no excuse for equipment to be used in circumstances where the airstream carries the spray directly onto a passer by or neighbouring property. Advance information about the proposed work can also contribute to a better understanding between the grower and members of the public.

The Code of Practice gives some indication of the optimum wind conditions for crop spraying. It is however disappointing that few growers make regular use of instruments such as anemometers for measuring wind speed and all the more so since this was one of the recommendations of the 1983 BCPC study into herbicide drift (Elliott and Wilson 1983).

An adequately trained and instructed operator should be able to ensure that incidents of direct overspraying do not occur. The problems of spray drift must also be considered; in today's countryside the level of drift from many air-blast machines is unacceptable. The trend of incidents indicated in Table 2 indicates that more must be done to meet the requirements of the legislation.

Safeguarding the Environment

The duty under COPR is to take all reasonable precautions to safeguard the environment and in particular to avoid pollution of water. This suggests the need for active steps to avoid environmental damage. Many air-assisted spraying operations are currently carried out in ways which contradict that responsibility. Careful consideration is needed to determine an acceptable means of spraying an orchard that will produce good, uniform coverage of the target and no drift. Droplets with a volume median diameter (VMD) of between 120-300 microns are produced by many air-blast sprayers but in the high velocity airstream, secondary atomization is likely to reduce their size to a significant extent. Those machines which are designed to propel droplets up to 15 metres high in an arch of 270^{o}, clearly have a considerable potential for causing drift.

Action to safeguard the environment needs to take account of the likelihood of offsite drift and what its affects might be. The environmental effects of drift will depend on where it falls. Much of the available information relates to damage caused by the drift of hormone herbicides applied by ground crop sprayers and to which many cultivated plants show a significant sensitivity. Similar effects are likely to be found on native species and garden crops. Effects of insecticide and fungicide drift have been less well documented but honey bees in particular have been involved in numbers of pesticide incidents.

Factual evidence of environmental damage based on direct measurement of spray drift from air-assisted spraying has seldom been collated in a structured way. Some work (Holt et al 1976) has used bioasseys to suggest safe distances of 500 metres for air-assisted applications of certain herbicides. Such estimates are difficult to substantiate but recently there have been moves under the COPR pesticide approval system to attach separation distances to certain categories of pesticides eg fenpropathrin must not be applied by air-assisted sprayer equipment within 80 metres of surface waters and ditches.

Air assisted placement sprayers

In the main the problems discussed so far relate to air-blast machines. However sprayers which use a stream of air to carry the droplets down into the crop seem to be capable of overcoming many of the difficulties described. Indeed sales literature often claims control of drift as a positive advantage of such systems. It is however difficult to determine the contribution which they do actually make to health and safety.

Promotional claims for air-assisted placement sprayers emphasise that the technique will enable spraying to take place on days when the weather conditions would rule out use of conventional equipment; this is on the basis that the level of drift is the same at higher wind speeds as arise from standard machines at low wind speeds. Such claims assume that the level of drift from conventional spraying is acceptable; this may not always be the case. An alternative view would be that the better technology of air-assisted placement spraying should be used not to create the same level of drift in higher wind conditions, but instead, to give improvements and a reduction of the drift which arises at the recommended wind speed rates for ground crop spraying. This larger weather window is promoted in sales literature but it is misleading to claim it as a safety improvement.

Other issues including the problems which may arise from greater operator control of variables need special consideration with this equipment. However air-assisted placement sprayers do seem to offer significant potential for improvements in the control of risks from pesticide application.

CONCLUSIONS

The tenor of this paper suggests that on health and safety grounds the use of many air-assisted sprayers needs to be carefully examined if the requirements of recent legislation are to met.

In presenting it to this symposium I refer back to the final recommendation listed in British Crop Protection Council Occasional Publication No 3 which calls for a renewal of efforts to adequately train farmers and spray operators in efficient spray application. Drift prevention is an important part of this. Under COPR and COSHH for air assisted spraying this is now an imperative.

REFERENCES

Elliott, J G & Wilson, B J (eds) (1983). The influence of the weather efficiency and safety of pesticide application the drift of herbicides (BCPC occasional publication no 3). London BCPC.

Holt, H A (et al) (1976) Drift of tordon 155 mixture in a dormant season mist blower application (Down to Earth, 1, 1-16).

MAFF (1986) Survey of usage of pesticides in Agriculture, Horticulture and Animal Husbandry in England and Wales 1980-1983. Survey Report 41.

Morgan N G (1981) Minimising pesticide waste in orchard spraying (Outl Agric, 10, 342-344).

Walklate P J (1988) Transport physics of spray application to orchard crops (AFRC Spray Study Group Project Paper 88/231090).

PESTICIDE DRIFT FROM AIR-ASSISTED ORCHARD SPRAYERS - A NUMERICAL SIMULATION STUDY

P.J.WALKLATE

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

ABSTRACT

In this paper an atmospheric dispersion model (Walklate,1987) is used to simulate pesticide drift from a radial flow air-assisted orchard sprayer. The source of spray drift is represented in the model by the volume flux distributions with respect to height and droplet size, downwind of the physical position of the sprayer and beyond the influence of the local forced air flow. The model takes into account the effects of droplet inertia on turbulent transport, droplet evaporation, the effects of the crop and the efficiency of typical collectors used to measure drift. The model is used to examine the potential for reducing drift by limiting the height of the spray source to the crop height. For a typical sprayer equipped with hollow cone nozzles (droplet VMD of 140μm) the drift reduction effect of this is further enhanced by a factor of between 2.0 to 1.7 at up to 50m compared with a standard sprayer. The spray drift model is put forward as an effective alternative to drift assessment strategies for air-assisted sprayers based on measurement alone.

INTRODUCTION

Air-assisted orchard sprayers have recently come under scrutiny due to increased concern for pesticide contamination from spray drift. These machines were designed to utilize a forced air flow to enhance the transport of pesticide spray in densely foliated tree canopies (Byass & Weaving,1960; Byass & Charlton,1964 & 1965; Randall,1971 and Hale,1975 & 1978). However, during the past ten years, dramatic changes have been brought about in many commercial orchard systems by the replacement of large bush or standard trees with dwarf trees planted at high density. These changes have not been matched by the research to establish the forced air flow and spray distributions of spraying equipment to optimize deposition and minimize drift. As a result of this it is now common practice for these sprayers to create excessive drift during routine spraying due to the generation of forced air flow and spray distributions that are inappropriate for direct application of pesticides to most modern orchard systems. Although it is widely recognized that indirect spraying by deliberately creating spray drift can produce deposition distributions that are effective for some crop treatments. However, the present code of practice for pesticide application to crops restricts growers to the use of more direct methods of application that avoid the production of excessive drift.

Current experimental methodologies for assessing drift usually involve measuring the spray drift flux at a number of positions of interest downwind of the sprayer. This approach however is time consuming and may also be unsatisfactory from the point of view of making routine comparative assessments of different sprayers under controlled atmospheric conditions.

Alternative methodologies for assessing spray drift are being developed at AFRC Engineering based on computational models. The atmospheric drift model described in this paper requires measurements of the distribution of spray flux down wind of the sprayer to simulate a practical spraying system. This approach offers greater flexibility than a purely empirical based method for studying spray drift and makes effective use of limited field measurements.

In this paper the dispersion model is used to establish the reductions of spray drift that can be achieved by manipulating the source height and droplet size distribution of a typical orchard sprayer.

THEORY

In this study the problem of predicting atmospheric dispersion of spray from a few measurements of an air-assisted orchard sprayer is considered. It will be assumed that measurements of the spray volume flux distribution with height and droplet size are known, or can be measured, at some distance x_0 downwind of a sprayer. This information will then be used to calculate subsequent spray drift.

The airborne flux of spray droplets, measured by a drift collector can be expressed as:

$$F(x-x_0,z-z_0) = \iint V(z_0,D_0)\ p(x-x_0,z-z_0,D_0)\ dz_0\ dD_0 \qquad (1)$$

where V the initial probability density function of spray volume flux with height z_0 and droplet diameter D_0 at x_0 and p is the probability of transport of droplets from an initial source value at (x_0,z_0) to a down-wind collection point at (x,z).

The random-walk algorithm described by Walklate (1987) is used to calculate p in this paper from an ensemble of simulated droplet trajectories. This procedure produces solutions that are broadly equivalent to those given by other numerical and analytical strategies based on convection diffusion equations for spray concentration. However, random-walk models are usually simpler to formulate than these alternative models but usually involve more numerical computation.

LIMITATIONS OF THE THEORY

Evaporation effects can change the transport and impaction probabilities throughout space due to a reduction in the droplet size along each trajectory. For the purpose of this study it is assumed that typical pesticides used in orchard spraying are non-volatile and are carried by water which evaporates during the dispersion process. All calculations presented here are based on a pesticide concentration of 0.1% (i.e. a residual non-volatile droplet that is 10% of the original diameter). The quasi-stationary evaporation theory of Fuchs (1959) is incorporated into the model to estimate the change in droplet size with respect to time throughout the transport process. This gives an evaporation rate proportional to the wet bulb depression measured by a psychrometer and the droplet velocity relative to its surroundings. The calculations of evaporation based on this model serve as a worst case estimate of drift because the neglected effects of both surface tension which can become significant below 30μm (Zung,1967) and the vapour phase coupling of the air flow in the spray plume will in practice reduce the evaporation rate predicted by the model. On the other hand atmospheric turbulent dispersion characteristics of small droplets below 30μm are very similar for length-scales under consideration here (i.e. typically less than 100m from the source). The main difficulty encountered in modelling the very small droplets is due to inadequate knowledge of impaction characteristics of various crop surfaces.

Within the crop there are two possible sinks for the impaction of airborne droplet namely the ground and the crop itself. The impaction and deposition processes that give rise to the removal of spray droplets from an airborne suspension by the crop are accounted for in the model. This is given by the joint probability of the simulated droplets encountering a surface and the probability of impaction at that surface. This latter probability is also based on a similar impaction law for cylindrical collectors based on the data of May and Clifford (1967). For the purpose of the calculations present here the equivalent cylinder length-scale for the crop is assumed to be of the order of the projected leaf cross (i.e. typically 10mm). A Poisson distribution with the single trial probability proportional to area density has been used to model the effect of crop surface area on droplet transmission. Estimates of this were based on leaf area measurements on 2.5 m tall trees with a bulk leaf area index of 1.5.

DISCUSSION

The heavy particle dispersion model used for the calculations presented in this paper have been demonstrated by Walklate (1987) to give agreement with available laboratory experimental data on grid generated turbulence (Snyder and Lumley,1971). In addition to this Fig 1 shows that for particulate dispersion above crops the predicted plume height for non-volatile liquid droplets down-wind of a line source compare well with the experimental data.

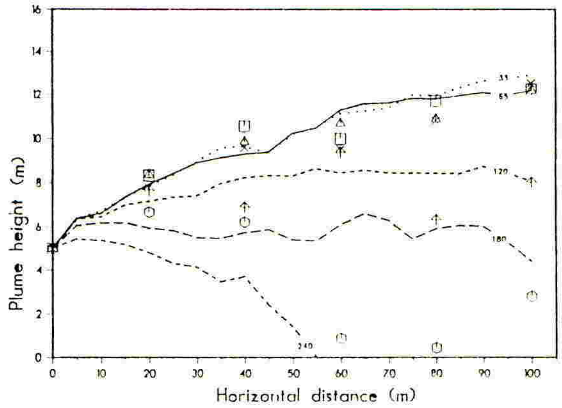


Fig.1. Maximum plume height at 10% of the concentration maximum against distance from the source. Experimental data of Lawson & UK (1979) for droplet size ranges (μm) ◻ 10-32; △ 33-64; × 65-119; ↑ 120-179; ⦶ 180-240. Solid and dotted lines show model predictions for the indicated size of droplet diameter.

Experimental inputs for drift simulations

For the purpose of this study it will be assumed that the source probability density function $V(z_0,D_0)$ in equation(1) is adequately represented by

$$V(z_0,D_0) = V_z(z_0)\ V_d(D_0)$$

where V_z and V_d are independent probability density functions of height and droplet size respectively. Fig 2a & b show histogram representations of these functions for a typical radial flow air-assisted orchard sprayer at x_0=8m.

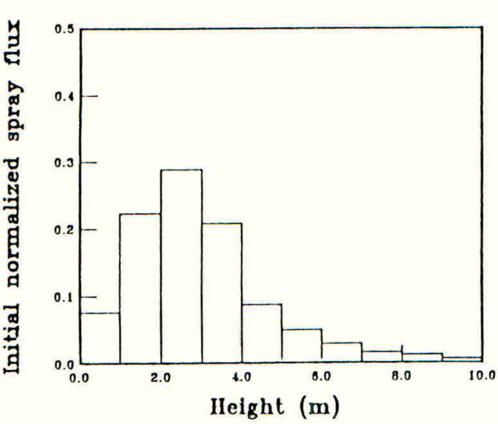


Fig 2a. Sprayer flux vs height

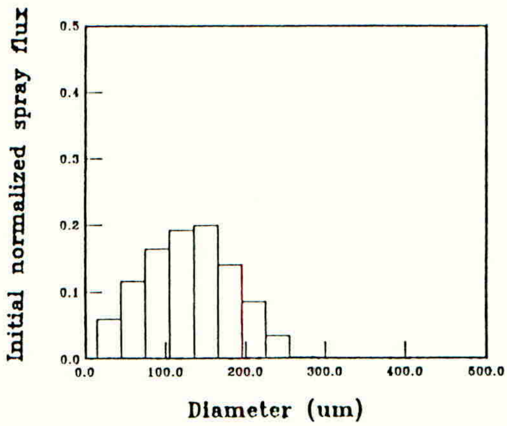


Fig 2b. Sprayer flux vs droplet size

Furthermore, to enable the calculation of the transport probability p in equation(1), estimates of vertical profiles of mean wind velocity and turbulence have been taken from measurements of a typical apple orchard canopy 2.5m high. All the simulations presented in this paper are for force 2 winds (i.e. a wind speed of 3 m/s at 10m and a shear velocity of 0.32 m/s with a crop height of 2.5m and a bulk leaf area index of 1.5).

Simulation of orchard sprayer perturbations

An attempt is made here to quantify the drift reductions that might be achieved by adjusting existing sprayers (i.e. by limiting the spray height near to the source to the crop height). The results are presented in Fig.3 for extreme evaporation conditions.

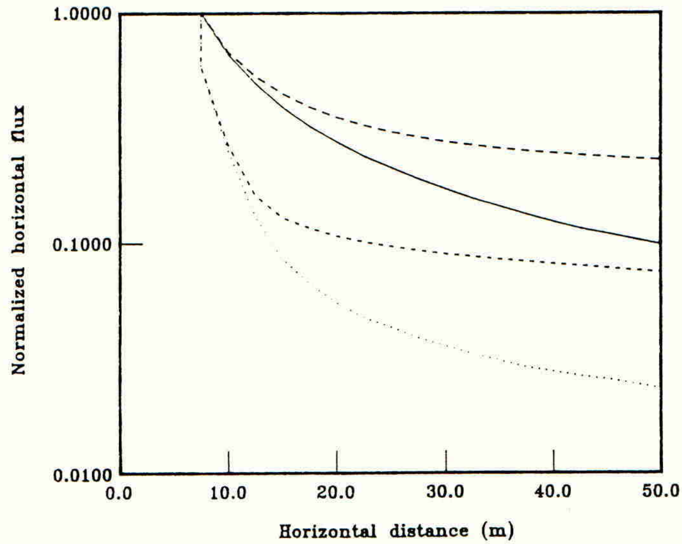


Fig 3. The predicted effect of initial height distribution and evaporation on spray drift

	Wet bulb depression	Spray height cut-off
——	0.0	10.0
......	0.0	2.5
----	7.0	2.5
---	7.0	10.0

In practice these modifications of the spray plume initial height could be achieved by adjusting both the volumetric air flow rate and its spatial distribution to match the target crop structure.

Fig 3 shows that beyond the initial condition at 8 m the effect of limiting the source height reduces spray drift as might be expected. Also, the effect of evaporation is shown to increase the levels of pesticide drift because smaller pesticide droplets are more easily suspended by atmospheric turbulence and have reduced impaction efficiency. Table 1 summarizes these reductions in spray drift for the two extreme evaporation condition. The calculations have neglected any difference in the airborne spray close to the sprayer that may also result from different evaporation conditions. Table 1 shows that by limiting the height of the spray plume to 2.5 m at 8 m from the sprayer an effective source flux reduction of 41% is achieved. In addition at 20 m the effective reduction in drift is predicted to be between 80% and 70% due to the effect of the crop. This demonstrates a useful amplification of the source perturbation (i.e. a gain of between 2.0 to 1.7 depending upon distance from the source and the humidity).

Table 1. The predicted effective drift reduction achieved by limiting the height of the drift plume to the crop height of 2.5 m for different evaporation conditions.

distance from sprayer (m)	(original drift - new drift)/original drift (%)	
	no evaporation (wet bulb depression = 0^c)	evaporation (wet bulb depression = 7^c)
8.0	41	41
12.5	74	70
20.0	80	70
30.0	80	68
40.0	78	67
50.0	76	68

Alternatively some drift reductions can be brought about by minimizing the proportion of small spray droplets. Table 2 shows the predicted fraction of each initial size droplet that is still airborne at 50m from the sprayer.

Table 2 The predicted % of airborne droplet flux at 50m from an orchard sprayer based on a spray flux height distribution given by Fig 2a

droplet size (μm)	Airborne flux at 50m as % of 8m	
	no evaporation (wet bulb depression = 0^c)	evaporation (wet bulb depression = 7^c)
60	30	66
90	10	44
120	3	15
150	0.8	3

Also, Fig 4 shows the predicted drift vs distance characteristics for an air-assisted sprayer with a source flux height distribution given by Fig 2a and various alternative nozzles. Firstly, these few simulations reinforce the advantage of an idealized CDA spraying systems (i.e. of mono-size droplets) over conventional hydraulic spraying systems for reducing drift. For example Fig 4 shows that the drift given by a typical hollow cone nozzle with a VMD of 140μm is equivalent to an idealized CDA system with a VMD of only 90 μm at 50m for zero wet bulb depression. The equivalent size for a CDA system increases to a VMD of 110μm by making a similar comparison with a wet bulb depression of 7 C. However, in practice it may be difficult to produce a mono-size spray at the exit from a typical air-assisted sprayer because the air flow is highly turbulent and with exit velocities of the order of 20 to 25 m/s this produces a high random force disturbance of the atomization process.

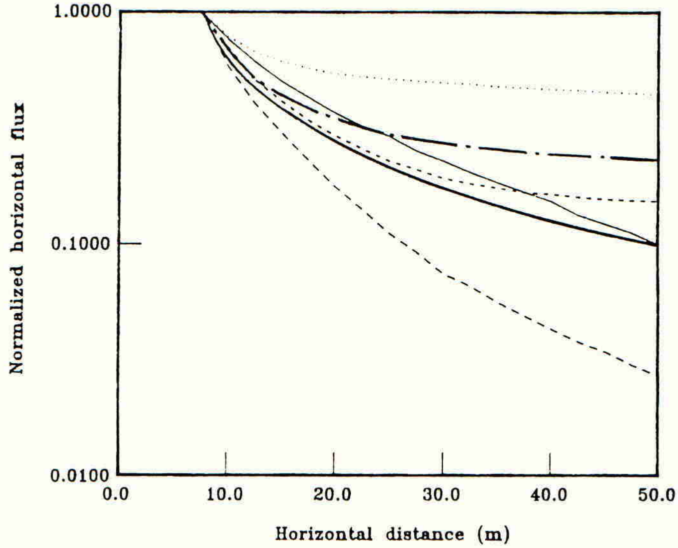


Fig 4. The predicted effect of initial droplet size distribution and evaporation on airborne spray flux

	Wet bulb depression	Droplet size VMD
	Idealized CDA	
——	0.0	90.0
········	7.0	90.0
-----	7.0	120.0
– – –	7.0	150.0
	Hollow cone	
—— (heavy)	0.0	140.0
—-	7.0	140.0

CONCLUSIONS

The computer simulations have shown that the height of the spray distribution near the source, the evaporation rate, the initial spray droplet size and the shape of the spray droplet size distribution can all have a significant influence on pesticide drift from orchard sprayers. Therefore the greatest potential for reducing drift is given by combining all possible control measures. However, the matching of the disturbed air flow to the crop coupled with suitable nozzle selection is probably the most practical combination of engineering controls that can be used to greatest effect in the immediate future. Additional chemical control can also bring about drift reductions by using anti-evaporants but raise additional questions related to their influence on biological efficacy.

The likely range of drift reductions that can be achieved by limiting the maximum source height in a force 2 wind and an orchard with 2.5 m tall trees with a leaf area index of 1.5 have been calculated. For these conditions eliminating the 41% of the total spray flux above the crop gives a maximum reduction in drift of between 70% and 80% at 20m. These drift reductions could be achieved in practice by modifying orchard spraying equipment to match the disturbed air flow and spray distribution to the crop structure.

FUTURE WORK

This will be to develop further the spray dispersion model to study the effect of the forced air flow close to the sprayer and the interactions between the crop and spray droplets. With such a model it will be possible to examine some of the benefits of specific sprayer design features from the point of view of local spray deposition and drift. To test the validity of such a model basic data is required to describe the interaction between the crop and forced air flow.

REFERENCES

Byass,J.B.;Weaving,G.S.(1960). A low-pressure air-blast nozzle and its application to fruit spraying. J.agric.Engng Res.,5,179-199.

Byass,J.B.;Charlton,G.K.(1964). Spray drift in apple orchards. J.agric.Engng Res.,9,48-59.

Byass,J.B.;Charlton,G.K.(1965). Spraying techniques for orchards of standard trees. J.agric.Engng Res.,10,60-69.

Fuch,N.A.(1959). Evaporation and droplet growth in gaseous media,Pergamon Press, London.

Hale,O.D.(1975) Development of a wind tunnel model technique for orchard spray application research. J.agric.Engng Res.,20 ,303-317.

Hale,O.D.(1978). Performance of air jets in relation to orchard sprayers. J.agric. Engng Res.,23,1-16.

Lawson,T.J.; UK,S.(1979). The influence of wind turbulence, crop characteristics and flying height on the dispersal of aerial spray, Atmospheric Environment. 13, 711-715.

May, K.R.; Clifford,R.(1967). The impaction of aerosol particles on cylinders, spheres, ribbons and discs, Ann. Occup. Hyg., 10, 83-95.

Randall,J.M.(1971). The relationship between air volume and pressure on spray distribution in fruit trees. J.agric.Engng Res., 16, 1-31.

Snyder,W.H.; Lumley,J.L.(1971). Some measurements of particle velocity autocorrelation functions in a turbulent flow, J.Fluid Mech., 48, 41-71.

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

Zung,J.T.(1967). Evaporation rate and lifetime of clouds and sprays in air - The cellular model, J. Chem. Physics, 46, 6, 2064-2070.

DRIFT OF CHARGED AND UNCHARGED SPRAY DROPLETS FROM AN EXPERIMENTAL AIR-ASSISTED SPRAYER

N.M. WESTERN and E.C. HISLOP

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

ABSTRACT

A wind tunnel has been used to measure drift from an experimental air-assisted sprayer, designed at the AFRC Institute of Engineering Research. Fine spray droplets from an F80/0.2/3.0 atomiser were examined, with and without electrostatic charge, using air assistance of 5.2, 6.7 and 8.3 m/s at crop height. At windspeeds of 2, 3 and 4 m/s spray drift increased with windspeed but was reduced at all levels of air-assistance. Electrostatic charging of spray droplets resulted in slightly increased drift.

INTRODUCTION

Over recent years there have been increasing economic and environmental pressures to develop pesticide application techniques that will improve the efficiency of agricultural spraying. Economic pressures to reduce the cost of expensive crop protection chemicals have led to the widespread use of reduced dose rates, which if they are to be as effective as full rates must be applied more efficiently. Secondly, the logistic need to apply sprays to large areas of crop in a limited weather 'window' has necessitated the use of reduced spray volumes. Both of these constraints, to a greater or lesser extent, require the use of small spray droplets. In the case of reduced dose rates, the large droplets in the spectrum carry a large proportion of the spray volume but are relatively poorly retained by foliage. In the case of reduced volume spraying, drop size must obviously be reduced to maintain a sufficiently high number of droplets to cover the target.

With these needs in mind, much effort has been put into the development of techniques that can alter spray drop trajectory and deposition, such as electrostatic charging. Equipment has also been developed that can physically open the crop canopy to improve spray penetration, reducing drift by virtue of the lower boom height. The most recent technique to be applied is air-assistance, as used for many years in spraying tree crops. Commercial equipment utilising this technology is now available from several manufacturers.

Results obtained for spray drift from air-assisted systems under field conditions are variable. Cooke et al. (1990) showed that the Degania sprayer, using fine atomisers and reduced volumes, gave drift which was up to 15 times greater than that from non-air-assisted higher volume coarser sprays, albeit under specified but sub-optimal conditions of boom height, air speed and crop morphology. However, with these parameters optimised, varying air speed from 25 m/s to 36 m/s showed a two-fold decrease in drift. Work reported by Taylor and Andersen (1989) demonstrated that the Hardi Twin air-assistance sprayer reduced spray drift by over 60% at 200 l/ha and by nearly 70% at 100 l/ha compared with a non-air-assisted spray of the same droplet spectrum. They also showed that the drift from the air-assisted spray at 100 l/ha was similar to that of a non-air-assisted application at 200 l/ha.

The present study assesses the potential, under variable wind speed conditions, of different rates of air-assistance and/or electrostatic charging to reduce spray drift.

MATERIALS AND METHODS

The air-assistance used in our study was provided by an experimental air injector (Fig.1) designed and built at the AFRC Institute of Engineering Research (IER), Silsoe to examine the potential for drift reduction and the scope for increased deposition. In contrast to other boom-mounted air systems, which use fans to produce high volumes of air, this injector uses a small volume of compressed air moving at high speed between two aerofoil surfaces to entrain a larger volume of air. The compressed air emerges from 500 0.5 mm diameter holes at 2.0 mm centres in the underside of the tube. Air pressure in the tube was maintained at 12, 16 and 30 kPa to give air speeds as detailed in Fig.2.

The single F80/0.2/3.0 atomiser (Spraying Systems 800050) was positioned in the centre of the air stream, 15 cm below the air outlet. The electrostatic charging system was similar to that described by Pay (1984), with electrodes positioned 14mm below the atomiser, 7mm each side of the spray fan, and held at c. 4 kV, giving a charge/mass ratio of c. 0.6 mC/kg.

All spray drift measurements were made in a spray chamber (Hislop, 1989; Western and Hislop 1989) with the spray boom static and perpendicular to the direction of the wind. Measurements were made with the chamber full of outdoor, tray-grown winter wheat in ear c.90 cm high, with the atomiser 40 cm above the top of the crop. Drift was collected on eight horizontal two-ply, Bri-nylon knitting yarn lines (Hayfield Textiles Ltd.) 7 m downwind of the atomiser at heights from 0 to 80 cm above the top of crop. Earthed spray collectors used the same knitting yarn lines in conjunction with 5amp fuse-wire.

The spray solution in all cases was 0.025% w/v sodium fluorescein and 0.1% w/v Agral 90 in tap water. Fluorescein tracer deposited on each drift collector was extracted in 0.05M sodium hydroxide and measured by spectrofluorimetry. Results are presented as total drift on all collectors in ug/g of tracer sprayed.

Wind speeds were measured using a calibrated hot-wire anemometer (PSI Ltd.) at nozzle height and 3.5 m downwind. The effect of wind speeds of 2, 3 and 4 m/s were examined.

Spray drop sizes and velocities were determined using an Aerometrics Phase Doppler Particle Analyser (Aerometrics Inc., USA), producing a temporal sample. Measurements were made 40cm below the atomiser as a single scan through the long axis of the fan, using a spray solution of 0.1% Agral 90 in tap water. The data (Table 1) are the mean values of three replicates.

RESULTS

Fig.2 shows air speeds measured at 10cm intervals along the length of the outlet 0, 15, 30 and 55 cm below the outlet with the maximum injector air pressure of 30 kPa. Mean air speed varied from 8.3 m/s at the outlet to 4.1 m/s at crop height, 55 cm below the outlet. Air speed was variable across the injector, with a marked decrease to the right of centre, becoming worse at greater distances from the outlet. This variability could have resulted from incorrectly drilled holes or, since the measurements were made after completion of the tests, to a partial blockage. Preliminary air speed measurements made at the Institute of Engineering Research before the tests showed a similar, but less pronounced, trend. The width of the air curtain decreased with distance due to aerodynamic drag from still air at the edges; this necessitated the use of a single atomiser to ensure that the whole width of the spray fan was entrained in the air.

The droplet spectrum (Table 1) showed that the atomiser falls into the BCPC 'very fine' or 'fine' categories. This type of droplet spectrum, although dissimilar to field spraying nozzles, was selected because the small droplets (VMD=129 um and 28% volume in droplets less than 100 um diameter) would increase the drift potential of the spray. These two factors, combined with the low velocity of the small droplets (c. 2.2 m/s) should enhance any effect of electrostatic charging.

All tests showed that spray drift, as ug/g of tracer applied, increased with windspeed, and decreased with air-assistance (Fig.3 and Fig.4). At a windspeed of 2 m/s, spray drift from the standard spray (no air-assistance and no electrostatic charge) was reduced by 71.8% with minimum air-assistance and by 88.3% at the maximum. At 3 m/s these reductions were 43.9% and 83.4% respectively; at 4 m/s drift reduction varied from 26.5% to 62.7%, respectively. At the three windspeeds used the mean drift reduction by the lowest amount of air-assistance (12 kPa injector pressure, 5.2 m/s air speed at outlet) was 47.4%, at the intermediate setting (16 kPa, 6.7 m/s) 60.6% and at the highest (30 kPa, 8.3 m/s) 78.1%. With charged droplets the reduction in spray drift, although following similar trends, was smaller, viz., 42% (-5.4%) at 2.0 m/s, 53.6% (-7.0%) at 3.0 m/s and 68.7% (-9.4%) at 4.0 m/s.

In all cases electrostatic charging of droplets appeared to reduce the drift control effectiveness of air-assistance. However, Johnstone et al. (1982) showed that under laboratory conditions charged sprays were preferentially attracted to collectors. To investigate this possibility we used four pairs of earthed and unearthed collecting lines, separated by 1 cm, at 20, 40, 60 and 80 cm above crop height, and sprayed charged and uncharged droplets. The results of this brief experiment (Table 2) showed that for unearthed collectors, as used in the drift measurements, collection of charged droplets was slightly reduced (-10.4% +/-1.95) compared with the capture of uncharged sprays. Comparing the drift captured on earthed collectors, charged sprays gave higher recoveries than uncharged sprays (+59.9% +/- 4.2). There was a small reduction (-1.6% +/- 0.5) in capture on unearthed collectors compared with earthed collectors when spraying uncharged droplets. There was also a tendency for a greater proportion of the charged droplets to be collected at 60 and 80 cm above the crop.

DISCUSSION

We have presented some evidence that air-assistance can dramatically reduce spray drift under a wide range of operating conditions. Using air-assistance, the use of fine sprays and, therefore, reduced application volumes should be possible without necessarily increasing the environmental hazards.

However, electrostatically charging droplets, although it may lead to enhanced spray deposition, either as total deposit or within crop distribution, did not reduce drift in our wind tunnel experiments. This conclusion is at variance with the findings of Sharp (1984), obtained from field tests, but similar to those of

Miller (1989). Increased drift is most likely to be due to the mutual repulsion of small, highly charged, droplets driving spray upwards.

REFERENCES

Cooke B.K., Hislop E.C., Herrington P.J., Western N.M. and Humpherson-Jones F. (1990). Air-assisted Spraying of Arable Crops in Relation to Deposition, Drift and Pesticide Performance. Crop Protection **9**, 303-311.

Hislop E.C. (1989). Crop Spraying Under Controlled Conditions. Comparing Laboratory and Field Pesticide Performance. Aspects of Applied Biology **21**, 119-120.

Johnstone R., Cooper J.F., Gledhill J.A. and Jowah P. (1982). Preliminary Trials to Examine the Drift of Charged Spray Droplets. Proceedings of the British Crop Protection Council Conference - Weeds 1982 **3**, 1025-1032.

Miller P.C.H. (1989) The Field Performance of Electrostatically Charged Hydraulic Nozzle Sprayers. Proceedings of the 4th EWRS Mediterranean Symposium 324-333

Pay C.C. (1984). Testing the Performance of a new Electrostatic Spraying System. Proceedings of the British Crop Protection Council Conference - Pests and Diseases 1984 **3**, 1013-1019.

Sharp R.B. (1984). Comparison of Drift from Charged and Uncharged Sprays. Proceedings of the British Crop Protection Council Conference - Pests and Disease 1984 **3**, 1027-1031

Taylor W.A. and Andersen P.G. (1989). The use of Air-assistance in a Field Crop Sprayer to Reduce Drift and Modify Drop Trajectories. Proceedings of the Brighton Crop Protection Conference - Weeds 1989 **2**, 631-639.

Western N.M. and Hislop E.C. (1989). Comparative Drift Measurements for BCPC Reference Nozzles and for an Airtec Twin-Fluid Nozzle under Controlled Conditions. Proceedings of the Brighton Crop Protection Conference - Weeds 1989 **2**, 641-648

Table 1. DROPLET SPECTRUM OF F80/0.2/3.0 ATOMISER

Atomiser	80050
Pressure	475 kPa
Flow rate	0.25 l/min
Volume median diameter	129.0 um
Number median diameter	33.0 um
V (10)	71.2 um
V (90)	189.7 um
% Vol. <50 um diameter	3.7
% Vol. <100 um diameter	28.0
Drop velocity at 50 um	2.1 m/s
Drop velocity at 100 um	2.2 m/s
Mean drop velocity	5.9 m/s

Table 2. EFFECT OF USING EARTHED OR UNEARTHED COLLECTORS ON CAPTURE OF SPRAY DRIFT (as ug/g emitted)

	Height above crop (cm)	Uncharged spray Expt.1	Uncharged spray Expt.2	Charged spray Expt.1	Charged spray Expt.2
Unearthed collector	80	6.3	8.1	17.2	14.2
	60	18.3	20.7	25.8	30.0
	40	45.7	52.2	39.1	54.7
	20	95.3	103.3	63.2	69.9
Total		165.6	184.3	145.3	168.8
		mean 175.0 sd. 9.4		mean 157.1 sd. 11.8	
Earthed collector	80	8.0	9.1	27.0	32.3
	60	18.2	21.7	32.5	49.5
	40	44.2	54.4	67.7	75.7
	20	94.3	95.2	99.0	119.1
Total		163.7	180.4	226.2	276.6
		mean 172.1 sd. 8.4		mean 251.4 sd. 25.2	

Fig.1. DIAGRAMMATIC CONSTRUCTION OF AIR INJECTOR

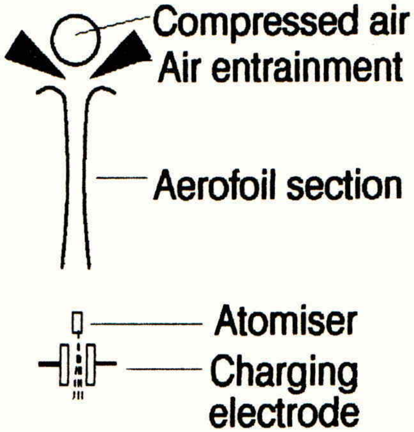
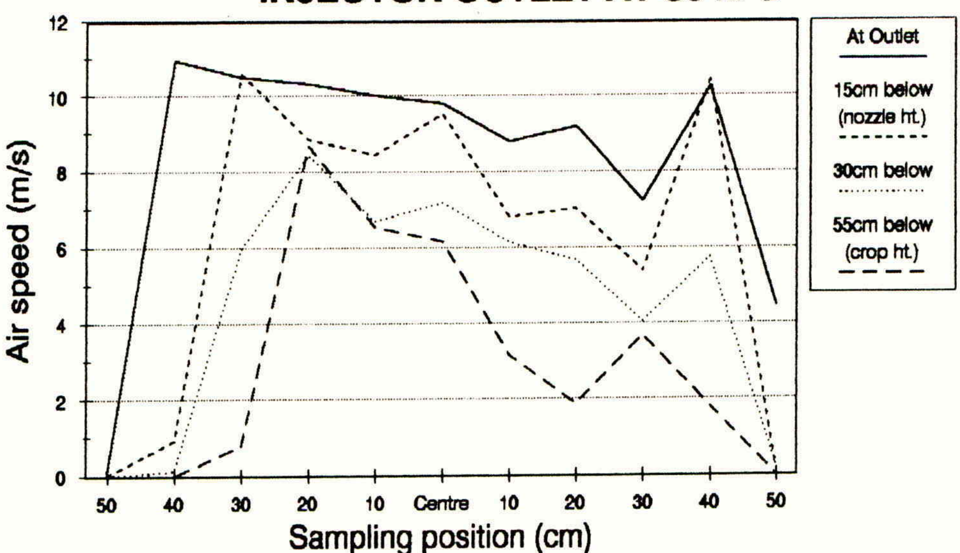


Fig.2. AIR SPEED MEASURED ACROSS INJECTOR OUTLET AT 30 kPa



Note: Each sampling point is the average for 10 seconds

Fig.3. SPRAY DRIFT AT 7m DOWNWIND AS ug/g OF TRACER EMITTED FROM NOZZLE

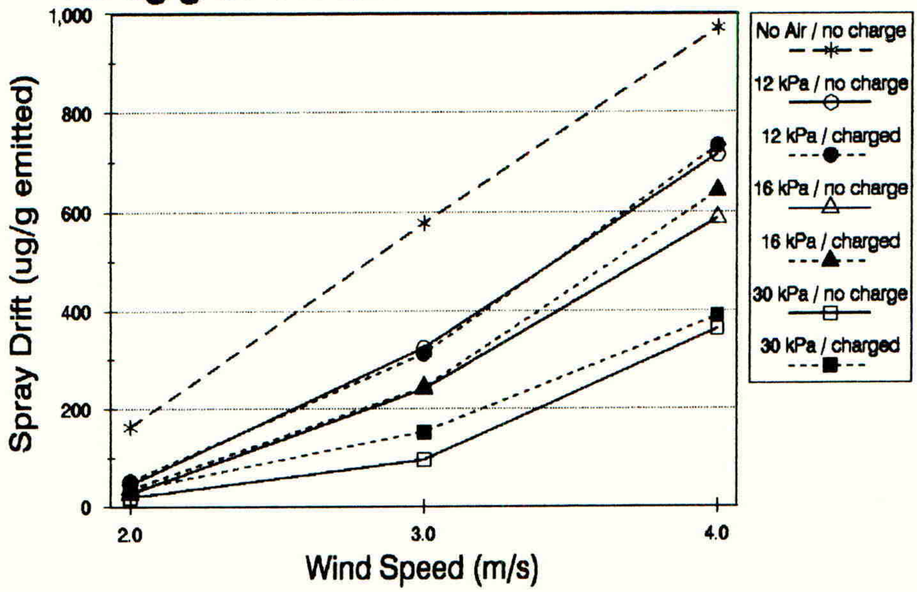
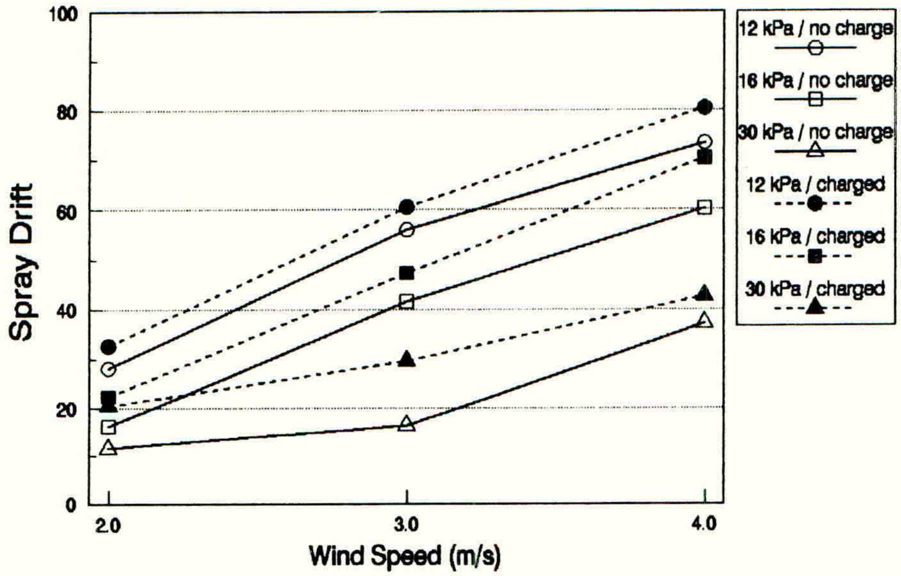


Fig.4. SPRAY DRIFT AT 7m DOWNWIND AS % OF DRIFT WITH NO AIR-ASSISTANCE OR CHARGE



A METHOD FOR ASSESSING THE DRIFT POTENTIAL OF HYDRAULIC NOZZLE SPRAY CLOUDS, AND THE EFFECT OF AIR ASSISTANCE

B. W. YOUNG

ICI Agrochemicals, Jealott's Hill Research Station, Bracknell, Berkshire, RG12 6EY, UK.

ABSTRACT

During the forward motion of the spray from a flat-fan nozzle, inwardly curling vortices are formed on either side as a result of the airflow round the moving spray cloud. The small droplets that are normally entrained within a static spray are drawn out to form a low energy trailing plume. This may subsequently become available to drift away from the intended target. A two-dimensional patternator has been developed to assess the magnitude of the trailing plume from a stationary nozzle in a head-wind. This is expressed as the Drift Potential. Data correlating the droplet spectra to the Drift Potential for a range of nozzles are presented. The effect of air-assistance (as the Hardi 'TWIN' system and the Clearacres 'AIRTEC' system) on the spray characteristics and subsequent Drift Potentials has been studied. The benefits of each system are discussed.

INTRODUCTION

The ever increasing sensitivity to environmental issues is moving the focus of attention in the application of pesticides - more concern is now shown for the fate of the portion that missed the intended target than for the efficiency with which the majority of the pesticide does its job. Off-target drift and the potential for damage to other crops, the local environment, animals and humans is becoming a key issue in many areas. In the USA the present EPA requirements for registration of a new product are forcing the agrochemical industry to provide extensive data regarding droplet characteristics and spray-drift evaluation studies. An intercompany 'Spray-Drift Task Force' has now been established in order to progress these issues (Hall & Holst 1990). These requirements will apply to all types of spray applications - aerial, mistblower, overhead sprinkler and ground-based systems. Similar concerns and pressures are building up in the UK and Europe.

It is immediately obvious to anyone who has watched a tractor sprayer in action in the field that not all of the spray output is deposited immediately under the boom on the intended target. A portion of the spray forms a cloud behind the boom that may be picked up by the air turbulence and ambient wind and blown across the field. The concerns about 'spray-drift' are to do with the magnitude and ultimate fate of this spray cloud. Much present effort is therefore addressed at how to quantify, control, predict (and preferably eliminate) this. The problem is not, of course, a new one, merely one that has always been there; but has of late been siezed upon by environmentalists as an area of prime concern. It is nearly forty years since the 'Nodrif Boom' was demonstrated to significantly reduce spray drift in windy situations by

Edwards and Ripper (1953). Five years ago the 'Windproof Sprayer' was developed in Canada along similar lines (Rogers and Ford, 1985) by shielding the nozzles and spray cloud. This system is now marketed in several forms.

Other mechanical techniques for increasing deposition - and consequently reducing drift - include the Croptilter and Tiltjets from Ciba Geigy Ltd., the Twin system from Hardi Int., and the Airtec from Clearacres Ltd. In these and other systems the aim is to maximise deposition and minimise the portion of the spray that is wasted to the environment. The questions that have to be answered are: What is the mechanism by which the fine component escapes from the bulk and how effective are these new ideas at minimising the escape? Much has been written on the origin of the driftable component of a spray and it is not intended to review the literature here; a comprehensive review of earlier literature has been made by Combellack (1982). Equally the physical and mechanical parameters of the process will not be elaborated on. However it is important to realise that it is the balance of the forces imparted on the spray during atomisation, the forward motion and the ambient wind that determine the magnitude of the driftable cloud.

There are three approaches to tackling the problem:

(a) to attempt to model the process.
(b) to attempt to directly measure drift in the field.
(c) to attempt to simulate the effect in the laboratory.

There is no doubt that modelling can play a valuable part in understanding the pattern of behaviour of spray clouds and models such as those by Thompson and Ley (1983) for long-range drift and by Miller and Hadfield (1988) for the formation and short-range behaviour have been developed. However, a model is only truly valuable if it accurately represents the total process under study. For example, in the latter model the following assumption is made.. "Trajectories were considered in two dimensions only, and effects due to the forward motion of the sprayer and the turbulent wakes created by this forward motion were neglected." In contrast Courshee (1959) states, "since the sprayer is moving at 4 mph or more the nozzle is in effect always in an airstream, and the fine drops are winnowed out into a cloud behind the spray." This effect has been demonstrated more recently by Gohlich (1983) and extended by Young (1990); who suggests that the source of the driftable droplets is actually the low energy trailing plume formed behind the moving spray cloud by entrainment of the fine droplets into the trailing vortices formed on either side.

This paper describes an attempt to quantify this effect in the laboratory with a view to predicting the likely behaviour in a field situation. The method is similar to that reported by Morgan <u>et al</u> (1957) and Alness (1986) in that an attempt is made to quantify the proportion of the spray landing on the immediate target area - and hence the amount potentially lost by difference - rather than the much more difficult task of quantifying the airborne cloud. The portion of the spray output that is not collected by this technique represents the amount that is potentially available for drifting to non-target areas. For convenience this is expressed by the term 'Drift Potential' (DP) which has been previously defined (Young 1990) as:-

"That proportion of the spray output from the nozzle that fails to be deposited within a defined plan area at a standard distance below the nozzle in an airflow of a defined speed."

Data are presented for a selection of typical flat-fan nozzles from the Hardi range and for the four BCPC Reference nozzles, and correlated with droplet size spectra. Measurements have also been made with a section of the Hardi TWIN system, to study the effect of the air curtain in enhancing deposition, and with the Cleanacres AIRTEC nozzle. In both cases the modification to the emitted spray cloud by the use of additional air has been correlated to the change in the measured Drift Potential. The possibilities that these systems may offer in reducing the potential damage to the environment - and more efficient use of chemical - are discussed.

EXPERIMENTAL METHODS

Spray chamber/wind tunnel

The droplet size data and Drift Potential measurements were carried out in a 6 m x 2.4 m x 2.4 m spray chamber fitted with an end-to-end air extraction system giving nominal air velocities of 0, 1 or 2 m/sec down the chamber at the nozzle. The airflow was not laminar in profile, but by conducting all measurements in the same position relative to the air inlet reproducible data could be obtained.

Droplet size analysis

A Particle Measuring Systems (PMS) Inc. model OAP-2D-GA1 probe with a size resolution of 14.5 microns per channel was used in conjunction with a model PDPS-11C data system using version 14 software as described previously (Young, 1990).

Conventional flat-fan nozzles

The single nozzle was mounted directly above the PMS probe such that the spray at the centre line of the fan passed vertically through the laser beam. The long axis of the fan was transverse to the laser beam (and also transverse to the airflow). The nozzle tip to laser beam distance was 40 cm. Measurements were only made at the one position, but it was felt this adequately reflected any change in performance between operating conditions or between nozzles. The central core of the fan is the region that contains the majority of the fine droplets and therefore the region of most interest. All measurements were made with tap water.

Airtec nozzle

A standard nozzle, with a No.35 restrictor, was used for all tests. It was mounted in the same manner as above, but inclined slightly such that the centreline spray cloud remained vertical. Accurate pressure gauges were fitted to the air and liquid supplies immediately adjacent to the nozzle to monitor the operating pressures. All measurements were made with tap water to overcome the complications of entrained bubbles in the spray droplets quoted as a feature when spraying surfactant solutions (Rutherford et al 1989). Collection and examination of samples in this study indicated minimal presence of air bubbles in the spray droplets.

Drift potential measurements

The method used was an extension of that described previously (Young 1990). In this case 63 open-topped containers were arranged in a 7 x 9 matrix (length x width) on a table at 50 cm below the nozzle and positioned such that the nozzle was directly above the centre container in the second row. The nozzle flow rate was measured by spraying into a graduated cylinder for one minute immediately before each test. The nozzle and airflow conditions were set with a collector held immediately under the nozzle above the empty containers. The spray was then emitted for the required time (3 to 8 minutes depending on nozzle output) and then the collector replaced. The containers were then individually weighed as before; from which the patternator profile and the Drift Potential were derived.

Measurements with the Hardi TWIN system
A 1.5 metre section of boom and air duct was provided by Hardi Int. The air was fed from a 19" fan through flexible tubing to the duct and gave an emission velocity of 30 m/sec; equivalent to the 'full air' setting on the normal equipment. The section was positioned such that the nozzle was in the same position as previously described, with the air duct pointing straight down.

RESULTS

BCPC reference nozzles

Data for the four Reference 110° nozzles are shown below. The PMS data has been both spatially and temporally resolved (Young and Bachalo, 1988) for comparison with previously published data (Doble et al 1985; Western et al 1989). The Drift Potentials were measured in a 2 m/s headwind.

TABLE 1. Summary data for BCPC reference nozzles.

Nozzle No.	Pressure (bar)	BCPC code	Spatial Data VMD	%<154 u	Temporal Data VMD	%<154 u	% Drift Potential
01-F110	4.5	VF/F	135	59.0	204	31.5	49.0
02-F110	3.5	F	239	28.4	305	11.0	28.0
04-F110	2.5	M	335	14.9	402	5.0	13.0
08-F110	2.0	C	454	6.4	500	2.1	8.5

Hardi nozzles

From previously recorded data it has been possible to derive the Hardi equivalent to the reference nozzles above. Data for these are shown in Table 2. Only the temporal data has been included because this has been found to be adequate. The Drift Potentials in a 2 m/s headwind have also been measured for these nozzles when used on the TWIN boom section.

TABLE 2. Summary data for equivalent Hardi nozzles (PMS temporal data)

Nozzle No.	Pressure (bar)	BCPC code	Temporal Data VMD	%<154 u	% Drift Potential	DP with TWIN boom
4110-10	4.0	VF/F	208	28.3	39.4	20.5
4110-14	2.0	F	299	10.6	23.0	14.3
4110-20	1.7	M	396	5.0	11.5	8.4
4110-30	1.5	C	487	2.4	7.8	6.6

Airtec nozzle

Data is given in Table 3 for a range of pressure settings, coded (1) to (5), all with a pressure difference of 0.69 bar (10 psi), and giving a flow rate of nominally 0.41 litre/min. This is typical of the use pattern being promoted for this nozzle (61 l/ha at 8 km/h) and is roughly equivalent in throughput to the Lurmark 01-F110.

TABLE 3. Summary data for Airtec nozzle (restrictor 35)

Pressure (bar) Air	Water	Flow rate litre/min	Temporal Data VMD	%<154 u	% Drift Potential	Derived BCPC code
2.76	3.45 (1)	0.42	186	39.8	43.7	VF
2.07	2.76 (2)	0.40	255	22.2	32.4	VF-F
1.38	2.07 (3)	0.41	370	7.3	21.5	F-M
1.03	1.72 (4)	0.41	448	4.7	17.3	M-C
0.69	1.38 (5)	0.40	515	1.5	12.3	C

DISCUSSION

The patternator data obtained by this technique is illustrated in Figure 1, using the Hardi 4110-20 nozzle as an example. The effect of the vortices on the downwind deposition can be seen in rows 4 to 7, with a transverse twin peak and central trough effect.

In contrast the effect of the air curtain from the TWIN system was to restrict virtually all of the deposition to two rows by eliminating the vortex effect and the trailing plume. In the case of the Airtec nozzle (as used here) there was no evidence of the twin peak effect, but rather a central plume extending behind the main fan. This is in agreement with previously reported observations (Western et al 1989).

The patternator data has been converted to a Drift Potential value in each case, and values are given in Tables 1 to 3 above. Data for the full range of Hardi 4110 series nozzles, at a range of pressures, has been obtained both with and without the TWIN air curtain in operation. This data is shown in Figure 2 plotted against the measured Volume Median Diameter (VMD). This shows a good correlation and also shows that the effect of the TWIN air curtain has a decreasing significance with increasing droplet size. This agrees with field drift data where the drift from the four BCPC size categories has been quantified with and without the air curtain (Taylor et al 1990). A similar correlation is obtained between the Drift Potential and the small droplet content of the spray (given as the percentage less than 154 microns in Tables 1 to 3). This might be expected since previous data (Young, 1990) has shown that the droplet size distribution of the trailing plume from any nozzle in this series is essentially constant. The Lurmark and Airtec data show similar correlation and thus strongly support the conclusions of Western et al (1989) and Lloyd and Bell (1984) that the magnitude of any driftable component is primarily related to the droplet size distribution of the emitted spray - or more simply, 'the finer the spray the worse the drift' Further support is given by data showing that the Drift Potentials. for 'Low Pressure' nozzles are significantly lower than for the equivalent standard nozzles - corresponding to the coarser size distributions of the former (Young 1990).

The proposal by BCPC to attempt to rank nozzles by a 'driftability index' (Miller 1990) is supported by the above results, from which is proposed that an equivalent Drift Quality be defined for the presently defined spray qualities as follows:

Very Fine = High Drift
Fine = Medium Drift
Medium = Low Drift
Coarse = Very Low Drift

In this way any spray that is compared to that from the standard nozzles will have a corresponding drift quality. While it must be stressed that the values reported here are a function of the equipment and procedure it is thought most probable that any assessment technique will give the same ranking provided the standard nozzles are used as reference points. The same argument applies to assessing the spray quality by using laser systems - different instruments give different numerical values, but the relative ranking is consistent. The spray qualities indicated in Figure 2 relate to the system and technique reported here.

For conventional flat-fan nozzles the droplet size distribution is closely tied to the liquid flow rate; from all the data obtained to date it is difficult to span more than one size category, by nozzle make or operating conditions, at a given flow rate. Thus a basic conflict exists - how to get a reduced volume spray that will not be more drift prone? The two pieces of equipment tested here offer distinctly different possibilities. The TWIN system has been shown to reduce the Drift Potential - by use of the air curtain - particularly for fine (and hence low volume) sprays. This effect is shown in Figure 3, where data for the four Hardi equivalent BCPC categories is shown, with and without the air curtain, and compared to the Lurmark reference nozzles. Drift quality windows have been set to correspond to the latter nozzles.

The data shows that the TWIN system will significantly 'safen' the very fine and the fine sprays with proportionally less effect on the other categories. This strongly supports the field drift evaluation (Taylor et al 1990).

In contrast the Airtec system offers a very significant - but radically different solution. The unique feature with the Airtec is that the spray quality can be radically altered at a given flow rate - data in Table 3 shows it is possible to span from very fine to coarse at 0.41 litres/min (61 l/ha at 8 km/h). The results in Figure 3 show that this system is capable of controlling the drift quality over two ranges (from high to low) by purely operational means, (ie. air and water pressures), thus giving the operator great flexibility to adjust to immediate conditions.

CONCLUSION

The work has shown that it is possible to relate the spray quality of a nozzle to a measure of its vulnerability to cause drift in the field. A means of assessing the drift quality in the laboratory has been established that is simple to use. Agreement with other published methods appears to be good. What is now needed is a sound data bank on the field drift of the reference nozzles under a range of conditions with which the laboratory data can be compared. Two points must be stressed regarding this work:-

(1) The numerical value of the Drift Potential - for example 30% - relates to the chosen collection area and does not mean that 30% of the output is going to drift away to be a major environmental hazard. Field data (Taylor 1990) suggests there is probably a factor of 10x involved. The measured values merely relate to what fails to be deposited on the immediate target area under the nozzle; as a convenient measurement parameter.

(2) As previously stressed (Young 1990) it is possible that the presence of formulation, adjuvants, oils etc. may significantly alter the behaviour - as is of course well known. What is very likely however is that the Drift quality will correspond to the spray quality resulting from the formulation in question.

REFERENCES

Alness, K. (1986) Vegetable oil as additive - droplet size and spray drift. *Proceedings 27th Swedish Weed Conference, Uppsala*. pp172-183.

Combellack, J.H (1982) Loss of herbicides from ground sprayers. *Weed Research*, **22**, 193-204.

Courshee, R.J. (1959) Reducing drift from ground sprayers. *SPAN, January*, pp 13-16.

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. *British Crop Protection Conference - Weeds 1985*, **3**, 1125-1133.

Edwards, C.J.; Ripper, W.E. (1953) Droplet size, rates of application and the avoidance of spray drift. *Proceedings British Weed Control Conference*, pp 348-367.

Gohlich, H. (1983) Assessment of spray drift on sloping vineyards. *Crop Protection*, **Vol 2**, No. 1, pp 37-49.

Hall, F.R.; Holst, R.W. (1990) Development of a generic database for use in predicting pesticide spray-drift. *IUPAC Conference, Hamburg, August 1990*, Paper 05D-13.

Lloyd, G.A.; Bell, G.J. (1983) Hydraulic nozzles : Comparative spray drift study. *MAFF study for the British Agrochemical Association.*

Miller, P.C.H. (1990) Personal communication.

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.

Morgan, M.J.; Rasmussen, L.W.; Orton, L.W.; (1957) The effects of wind on delivery patterns of nozzles used for weed spraying. *Weeds*, **5**, 350-361.

Rogers, R.B.; Ford, R.J.; (1985) Development of the Windproof Sprayer. *American Society of Agricultural Engineers, Summer Meeting,* E Lansing, Paper No 85-1003.

Rutherford, I.; Bell, G.J.; Freer, J.B.S.; Herrington, P.J.; Miller, P.C.H. (1989) An evaluation of chemical application systems. *Proceedings Brighton Crop Protection Conference - Weeds 1989*, 601-613.

Taylor, W.A.; Cooper, S.; Quanquin, B.J. (1990) The relationship between spray quality, wind speed and the use of air assistance with the 'Twin System'. Paper presented at 11th ASTM Pesticide Formulation and Application symposium, San Antonio, Texas. November 1990.

Thompson, N.; Ley, A.J. (1983) Estimating spray drift using a random-walk model of evaporating drops. *Journal of Agricultural Engineering Research*, **28**, 419-435.

Western, N.M.; Hislop, E.C.; Herrington, P.J.; Jones, E.I. (1989) Comparative drift measurements for BCPC reference hydraulic nozzles and for an Airtec twin-fluid nozzle under controlled conditions. *Proceedings Brighton Crop Protection Conference - Weeds 1989*, 641-648.

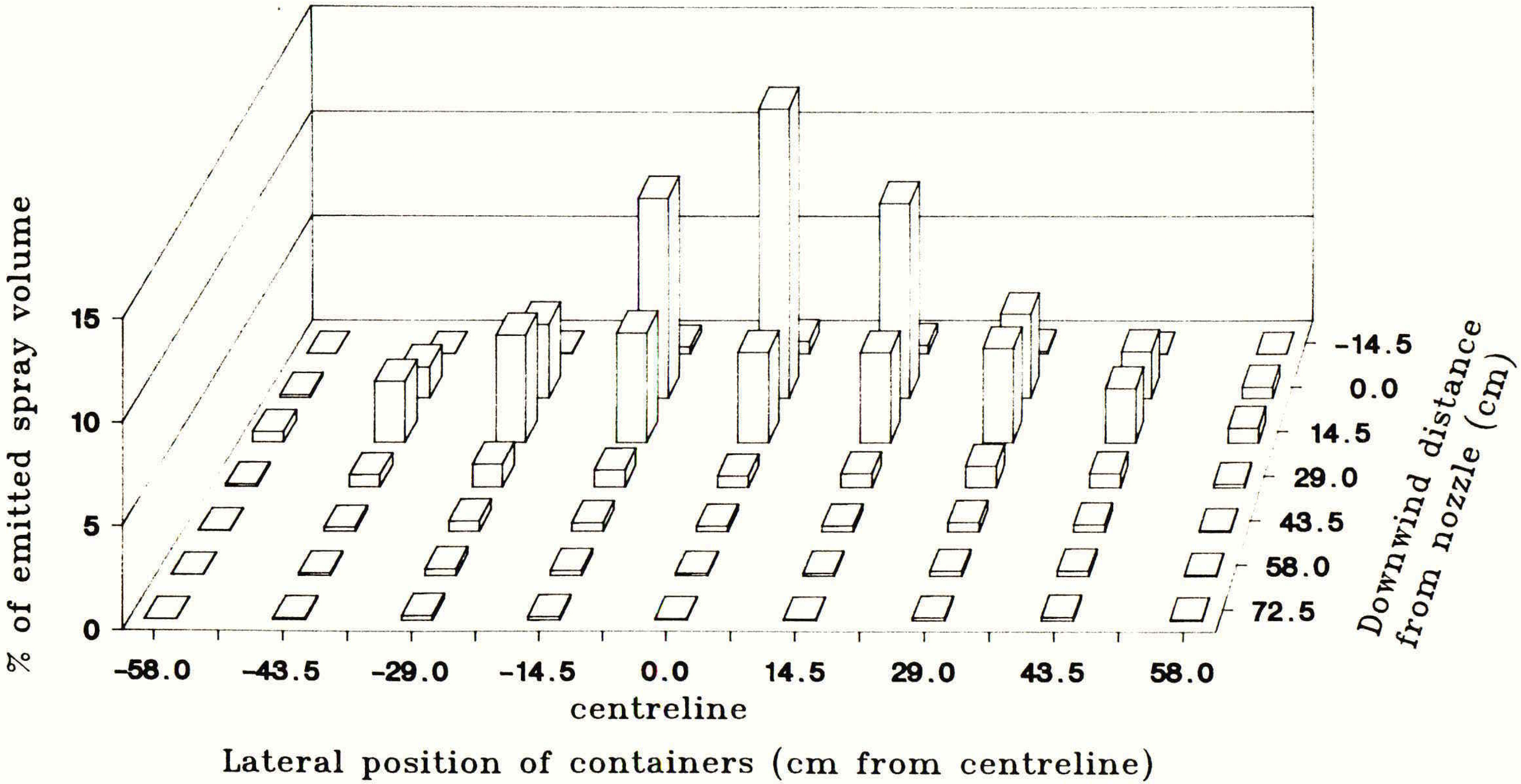
Young, B.W. (1990) Droplet dynamics in hydraulic nozzle spray clouds. *Formulations and Application Systems :* 10th Volume, ASTM STP1078, L.E. Bode, J.L. Hazen and D.G. Chasin, Eds. American Society for Testing and Materials, Philadelphia. 1990.

Young, B.W.; Bachalo, W. (1988) The direct comparison of three 'in-flight' droplet sizing techniques for pesticide spray research. *International Symposium on Optical Particle Sizing - Theory and Practice, Rouen, France.* Plenum Press. pp 438-498.

PRESENT ADDRESS:

Mr B.W. Young. Technical Services Manager - Spray Application, Dept. of Agriculture and Rural Affairs, Agricultural Engineering Centre, Princes Highway, Werribee 3030, Victoria, AUSTRALIA.

Figure 1. 2-D patternation for Hardi 4110-20 nozzle at 1.7 bar, 1.16 l/min, 50 cm height in 2m/s air flow



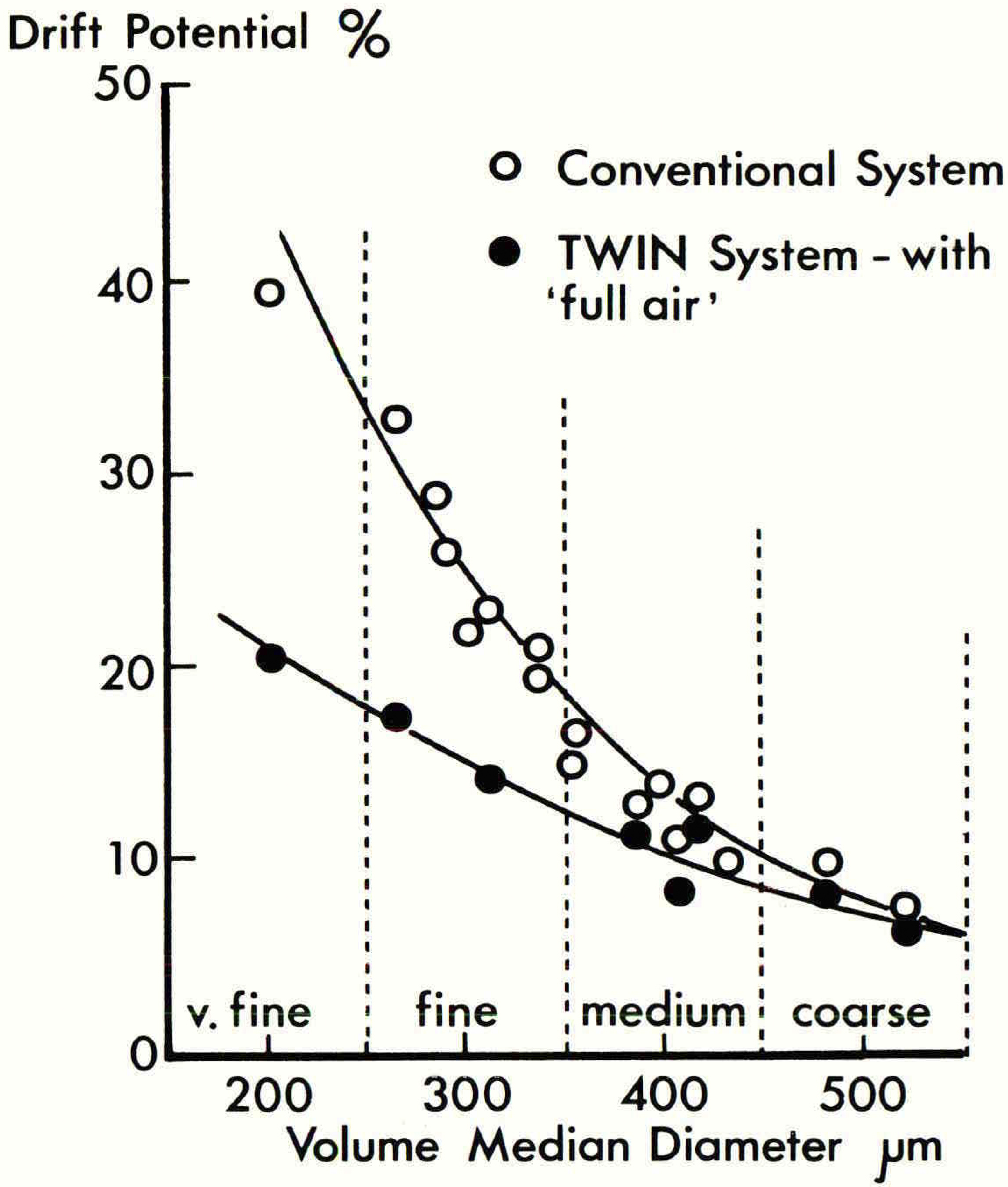


Figure 2. Data for Hardi 4110 series; showing the effect of the TWIN System.

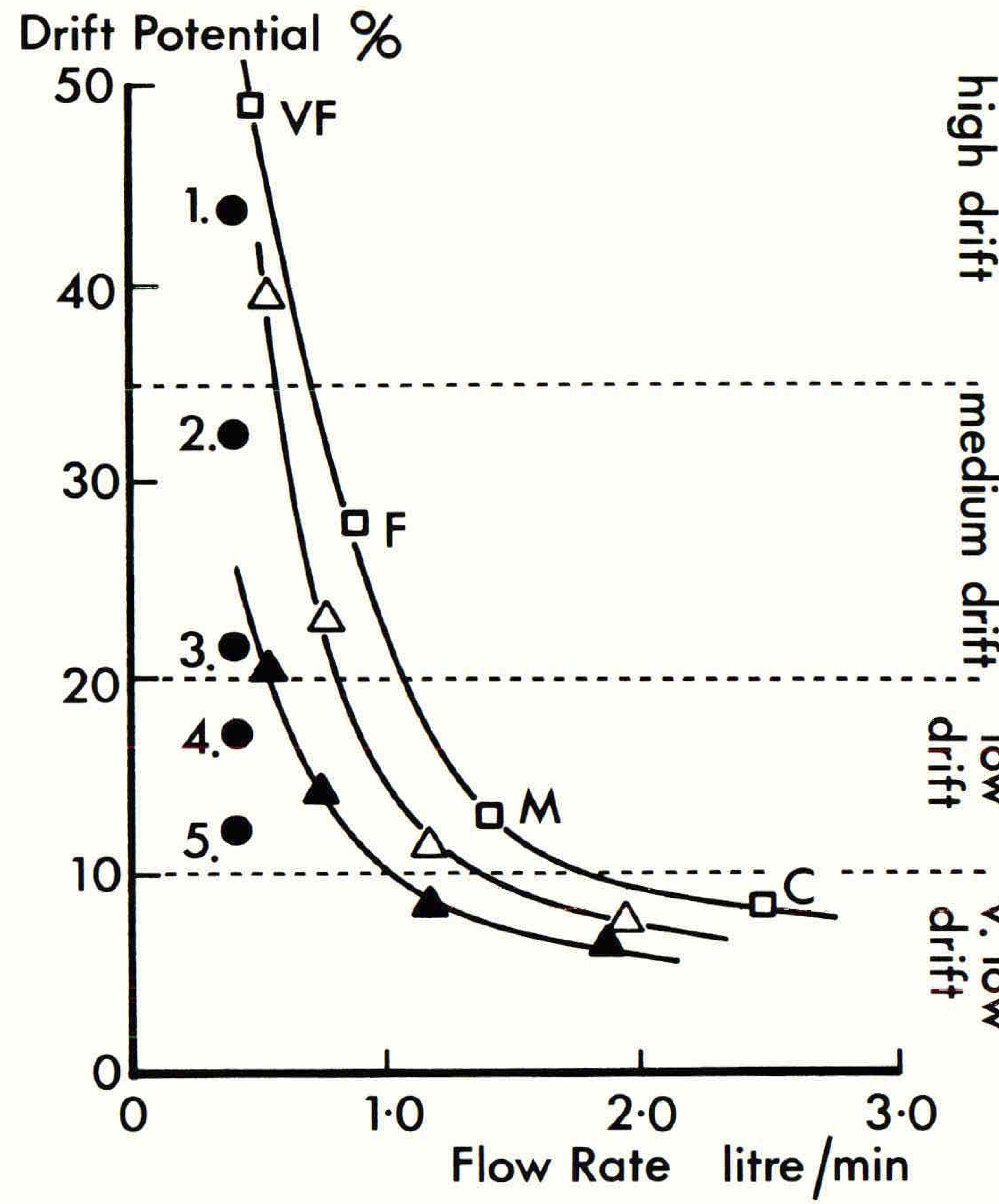


Figure 3. Drift Quality for selected nozzles: BCPC ref -- □; Hardi (no air) -- △, (+Twin) -- ▲; Airtec, settings 1 – 5 -- ●