POSTER SESSION P8E

SPRAY APPLICATION AND PRECISION TECHNOLOGY

Session Organiser: Professor Paul C H Miller
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Poster Papers: P8E-1 to P8E-5

Retention and bioefficacy with ethyl hydroxyethyl cellulose (EHEC) as a tank mix adjuvant to reduce spray drift

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ABSTRACT

EHEC is a cellulose polymer, modified for degree of substitution by ethyl and / or ethylene oxide units per anhydroglucose unit, which was previously demonstrated to favourably affect the atomization characteristic of agricultural crop sprays. This study demonstrates improvement and quantifies the advantages of EHEC over the older-technology drift additives, with particular attention to increased droplet retention and positive effects on bioefficacy.

INTRODUCTION

There is considerable interest in spray drift retardants among the agricultural community, driven by economics of on-target application and a growing concern for movement of the applied spray into or beyond the safety buffer zones. Beyond drift reduction, there are additional useful effects from certain viscoelastic polymers. Therefore, there are two distinct aspects for this publication, both relating the performance attributes of EHEC as compared to the old drift reduction polymers (polyacrylamide and hydroxy propyl guar). First is a discussion of droplet retention on biological targets, comparing the performance versus polymer concentration aspects. Second, the efficacy is documented for glyphosate herbicide on monocot species as affected by the presence of EHEC and two old technology polymers.

MATERIALS AND METHODS

Retention Studies

The polymeric materials and matrix of rates tested over this series of studies were:

EHEC BE-1	v. low *Mr*	0.75, 0.5, 0.25, .125, & 0.0625 % *wt/v*
EHEC EB-1	v. low *Mr*	0.5, 0.25, 0.125, 0.0625, & 0.03125 % *wt/v*
EHEC EK-2	low *Mr*	0.5, 0.25, 0.125, 0.0625, & 0.03125 % *wt/v*
EHEC H-22	low *Mr*	0.5, 0.25, 0.125, 0.0625, 0.03125, & 0.0156 % *wt/v*
EHEC HE-2	medium *Mr*	0.25, 0.125, 0.0625, 0.03125, & 0.0156 % *wt/v*
EHEC HK-2	medium *Mr*	0.25, 0.125, 0.0625, 0.03125, & 0.0156 % *wt/v*
EHEC HU-2	high *Mr*	0.25, 0.125, 0.0625, 0.03125, & 0.0156 % *wt/v*
EHEC K-22	high *Mr*	0.125, 0.0625, 0.03125, 0.0156, & 0.0078 % *wt/v*
Sta-Put [1]	polyacrylamide	0.0625% w/v polymer (3 qt. product/100 gal)
Strike-Zone DC[1]	hydroxypropyl guar	0.047% w/v polymer (6 oz product/100 gal)

[1] 'Sta-Put' and 'Strike-Zone DC' are products of the Helena Chemical Company, Memphis, TN, USA, and are representative of typical polyacrylamide and HP-guar chemistry-based drift reduction products. The range of EHEC molecular weight products and the chosen concentrations allow one to

examine the effect of polymer MW and polymer concentration on solution viscoelasticity and the resultant atomisation and deposition result.

Retention tests

'Roundup Original' (glyphosate; Monsanto) herbicide was added to the above polymer treatments at 12.5 ml/litre. All sprayed treatments contained 2 ml/litre 'Rhodamine WT' liquid to facilitate determination of retention. Applications were made in a track room through a Spraying Systems XR8003VS tip operated at 276 kPa (40 psi) and travelling at 14.4 km/h to give the equivalent of 83 litre/ha. Nozzle to target distance was 0.48m.

All barnyard grass (*Echinochloa crus-galli*) and wheat (*Triticum aestivum* L.) plants were grown in soil in 'Conetainers' (Stuewe & Sons, Corvallis, OR 97333, USA). Several seeds were germinated per cone and seedlings thinned to a single plant 7 days after germination. The plants were grown in a greenhouse under natural daylight conditions supplemented by overhead lighting 16 hours day with 8 hours night. Temperature ranged from 24 to 26°C. Plants were watered and fertilized with 1000 ppm 'Peter's Professional' 20:20:20 as needed for seedling establishment and healthy plant growth. The plants were used 21 days after sowing and were 7.5 to 12.5 cm tall.

Immediately after spraying the plants were removed from the track room. Each plant in turn was clipped at soil level and washed with 40 ml of 95% ethanol for 1 minute. Each wash solution was topped off to 50 ml in a volumetric flask, transferred to a snap top glass jar and stored in the dark to await analysis. The washed plants were placed in labelled paper bags and removed to a drying oven where they were dried for 24 h at 65° Celsius. For fluorescence determination analysis, an approximately 5 ml sub-sample was taken from each bottle and transferred to a 5-ml borosilicate culture tube which was placed in a labelled holder. The samples were analyzed for fluorescence with a 'Sequoia-Turner' Model 112 digital filter fluorimeter. Tracer quantity in each sample was determined from calibration curves generated from samples taken from each tank mix. All samples were analyzed within 12 h of spraying. Spray retention was determined for each of the two plant species and was expressed as µg dye per g dry weight of plant material. By using the herbicide concentration for each mixture the quantity of active ingredient retained by the plants was determined as µl spray retained x herbicide concentration.

Efficacy testing

Immediately after spraying (same protocol as above) the barnyard grass plants were removed from the track room and maintained in a greenhouse under natural daylight conditions supplemented by overhead lighting 16 hours day with 8 hours night. Temperature ranged from 24 to 26°C. Plants were watered and fertilized with 1000 ppm 'Peter's Professional' 20:20:20 as needed for healthy plant growth. After eight days the plants were harvested by clipping at soil level and immediately determining fresh weight. Subsequently, to determine dry weight, the same plant samples were removed to a drying oven where they were dried for 24 h at 65°C.

RESULTS AND DISCUSSION

The amount of spray material retained by a plant is a function of the amount of material impacting that plant minus the amount of material reflected. Droplet reflection is influenced by droplet size and liquid physical properties such as dynamic surface tension or other means of energy dissipation e.g., elasticity. Polymeric materials have frequently been shown to improve the retention of large droplets and can also influence retention by altering the trajectory of droplets within the spray cloud. It is likely therefore that polymer concentration will influence retention.

Retention Studies

Retention data for barnyard grass show that retention is improved somewhat by the inclusion of EHEC to the mixture (Figure 1). These data are consistent with results from tests and may be attributable to better adhesion. There was a trend (as might be expected) for greater retention with increased concentration for barnyard grass. There was directionally less retention from the older technology PAA and HP guar polymers, at their labelled rates, in this test.

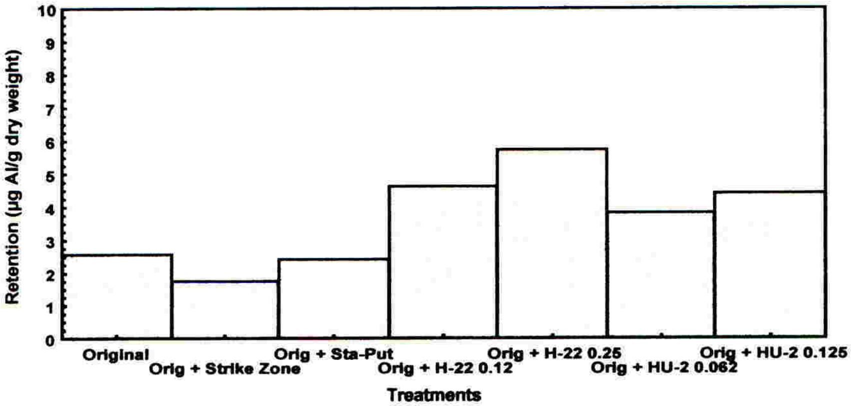

Figure 1. Retention of glyphosate on barnyard grass as modified by polymer additions

EHEC concentration by *M*r study

While we know that polymer concentration will influence retention, it may be that above a certain elasticity, an increased concentration would have little or even a decreased effect on retention, possibly due to run-off. This would account for the pattern observed when measuring retention as a function of polymer concentration. In this study, 8 EHEC polymers, ranging from very low to high *M*r, were examined at 5 concentrations each for retention on barnyard grass.

The data show a trend toward less retention at low rates followed by a plateau and finally a decline at the highest rate. Analysis of variance of the retention data showed that there was a two-way interaction between treatment (Polymer *M*r) and rate. The results for the treatments compared to the standards are shown as Figure 2. The data are expressed as µg a.i. per g dry weight. Comparisons between the polymers and each standard are shown as separate charts.

These data would suggest that there is an optimum range of molecular weight and concentration above and below which retention is reduced. This ideal range appears to be from mid level concentrations at low molecular weight to low concentrations at higher molecular weight. High concentrations did not appear to be as effective even at low molecular weights. Multiple regression analysis of the data showed that while the model was significant, the R^2 was quite low, suggesting that there are more influential components that were not evaluated here.

For each bar graph in Figure 3, the corresponding EHEC *M*r matches in this sequence:

Very Low *M*r		Low *M*r		Medium *M*r		High *M*r	
BE-1	EB-1	EK-2	H-22	HE-2	HK-2	HU-2	K-22

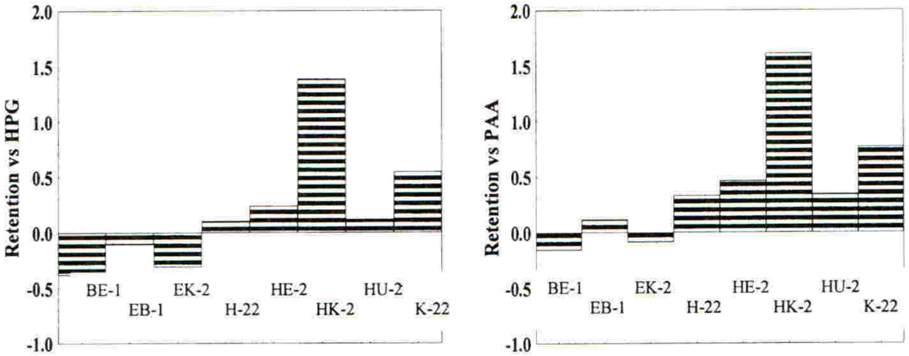

Figure 2. Relative retention of glyphosate on barnyard grass as affected by EHEC Mr; Two graphs of the EHEC range normalized against the retention of HP-guar + glyph.(left) and polyacrylamide (PAA) + glyph (right). Note the strong retention improvement from HK-2.

EHEC concentration effect on retention

The product by rate interaction (Figure 3) on wheat showed that EHEC HK-2 had a relatively flat rate response across the rates tested whereas data generated with the EHEC HU-2 showed that retention increased with increasing rate. The data for barnyard grass showed no significant treatment differences and the product by rate interaction results were similar to wheat.

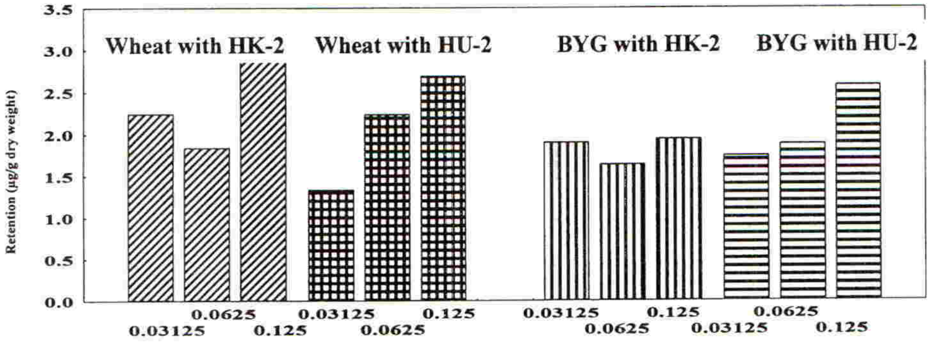

Figure 3. Retention of glyphosate on wheat and barnyard grass by rate and *M*r of EHEC

the r^2 was quite low (0.1653) suggesting, of course, that there are more influential components that were not evaluated here.

EHEC concentration effect on efficacy

A 3 dimensional surface plot (Figure 5) using rate as % *wt/v* shows a trend for greater retention with high rates of the lower molecular weight (*M*r) polymers and low rates of the higher *M*r polymers. These data are in line with findings from earlier experiments that suggested that there was an optimum *M*r and concentration range. This could be related to the spray cloud composition as well as the physico-chemical characteristics of the liquid that are interacting to modify the spray deposition. Note that efficacy (low values are good) aligns with good retention. Analysis of Variance of the combined efficacy data showed that there were no significant differences between the treatments F(3,120) = 0.09; p <0.9643. Nor were there any rate effects F(2,120) = 0.05; p <0.9483, nor interactions F(6,120) = 0.73; p <0.6246. The data in Figure 5 also suggest a similar trend to the efficacy data in that the best efficacy was obtained with high rates of the lower *M*r polymers and low rates of the higher *M*r polymers. The EHEC polymer designated HK-2 showed greatest retention potential.

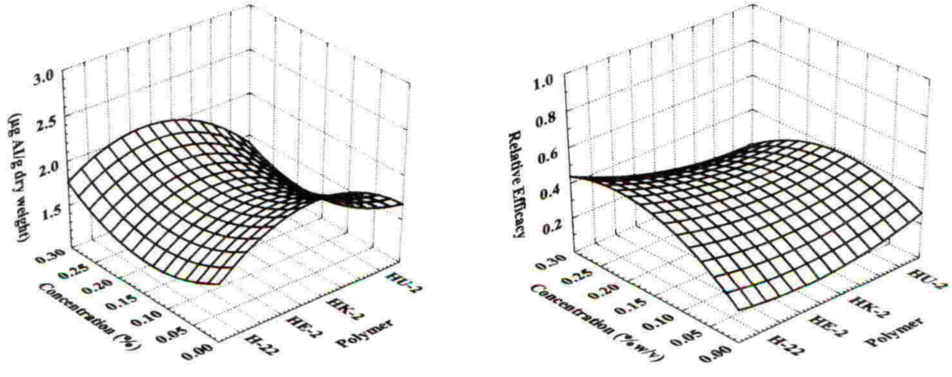

Figure 5. Surface plot of efficacy data (left) and retention (right) using % *wt/v* vs. molecular weight. Best retention is along a continuum from large amounts of a low *M*r polymer to small amounts of a high *Mr* polymer.

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Analysis of Variance of the combined efficacy data showed that there were no significant differences between the treatments F(3,120) = 0.09; p <0.9643. Nor were there any rate effects F(2,120) = 0.05; p <0.9483, nor interactions F(6,120) = 0.73; p <0.6246.

Efficacy

Bioefficacy test on barnyard grass

Earlier data had suggested that medium molecular weight/viscosity polymers used at medium rates were the most efficacy-favourable treatments. Therefore, in this study, we set out to attempt to confirm the result and conclusions from the previous test. Efficacy data based on fresh and dry weight measurements made 8 days after treatment show that there were no statistically significant differences between the treatments; F(6,21) = 2.48; p <0.0570 for barnyard grass. However, the data for barnyard grass (Figure 4) show a trend for improved efficacy compared to glyphosate alone when the EHEC polymers were added to the spray mixture.

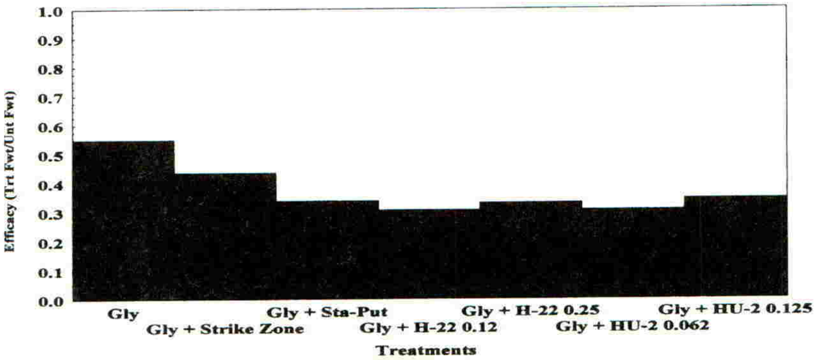

Figure 4. Relative efficacy of glyphosate on BYG as improved by viscoelastic polymers

EHEC concentration and molecular weight effect on efficacy

Analysis of the efficacy data showed no significant interaction between treatment (Polymer MW) and rate (F(28,160) = 0.84; p <0.6997) but it did show treatment differences F(7,160) = 6.43; p <0.0000. Rates were not significantly different F(4,160) = 1.31; p <0.2693. Overall, the data for rate show a trend toward low efficacy at low polymer rates followed by an increase and finally a decline at the highest rate.

The interaction between polymer molecular weight and concentration is perhaps more clearly illustrated in Figure 5 as a 3 dimensional surface plot. These data would suggest that there is an optimum range of molecular weight and concentration above and below which efficacy is reduced. This range appears to be from mid-level molecular weights with the poorest efficacy occurring at high concentrations of the higher molecular weight polymers. Multiple regression analysis of the data showed that while the model was significant F(7,686) = 5.194; p <0.0000)

Validation of wind tunnel methods for assessing the drift from agricultural spraying systems

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ABSTRACT

Studies examined the extent to which a tracer dye could bias the results of drift assessments by changing the droplet size distributions produced by six different nozzle conditions. Results showed that the addition of the dye did not change mean droplet sizes or the percentage of spray volume in droplets less than 100 µm. The repeatability of wind tunnel measurements was also studied using the same nozzle conditions. Measurements of vertical and horizontal airborne spray profiles were made in a wind tunnel on three separate occasions. The effect of immediately repeating measurements was also assessed. Results showed only small differences with different replicated measurements and it was concluded that wind tunnel experiments are a reasonably robust method of determining relative drift risk.

INTRODUCTION

Considerable effort has been directed at using wind tunnel approaches that can adequately define the risk of spray drift from agricultural applications systems (Phillips & Miller, 1999; Miller *et al.*, 1993). Previous work has also shown that the physical properties of the spray liquid substantially influence spray formation mechanisms with a range of nozzle types and hence change the risk of drift (Miller & Butler Ellis, 2000). However the effect of these and other factors influencing wind tunnel methodologies have not been widely studied. This paper set out to establish:

(a) if the addition of tracer dyes commonly used in wind tunnel and field studies of spray drift could be expected to influence the results obtained; and
(b) the effects of different replicated measurements in wind tunnel drift tests.

MATERIAL AND METHODS

The study used the nozzle conditions detailed in Table 1.

Measurements of droplet size distributions

Droplet size distributions were made using a Malvern Instruments 'Spraytec' analyser with measurements being made 350 mm below the nozzle when spraying water; water and tracer dye; water and adjuvant; water, adjuvant and tracer dye. The adjuvant used was 'Agral'

(Syngenta Crop Protection UK Ltd.) at 0.1% concentration and the tracer dye was 'Green S' (Merck Chemicals Ltd.) at a concentration of 0.2%.

Table 1. Nozzles and pressures used in the study

Nozzle type and description	Operating pressures, bar
Conventional flat fan - XR 11002	3.0 and 1.5
Pre-orifice flat fan – DG 11002	3.0
Pre-orifice deflector – TT 11002	3.0
Air induction – AI 11002	3.0
Hollow cone – TX VS10	4.0

To enable a representative sample to be taken within the spray, each nozzle was mounted on a computer controlled x-y transporter that was programmed to move the nozzle at 40 mm/s in a squared grid pattern such that the whole of the spray was sampled. The droplet size measurements were replicated three times.

Wind tunnel measurements of airborne spray profiles

Wind tunnel measurements were made based on the method described by Walklate *et al.* (2000), using a single nozzle at 0.6 m height, spraying for a 10 s duration, per replication, with saturated air conditions (80% relative humidity) and 2 m/s air velocity. The airborne spray was collected vertically at 0.1, 0.2, 0.3, 0.4 and 0.5 m heights at 2.0 m downwind of the nozzle and horizontally at 2.0, 3.0, 4.0, 5.0, 6.0 and 7.0 m downwind of the nozzle and at a height of 0.1m. Airborne spray profiles were measured using an array of 1.98 mm diameter polythene lines.

The effect of immediately repeating measurements in wind tunnel conditions on day 1 (paired measurements) was compared with fully replicated measurements made on three further separate days (2, 3 and 4). The repeatability of the measurements was then studied by comparing the means and standard deviations for four different combinations of replications:

A) all the replications of all occasions (5 replications);
B) both replications of day 1 (2 replications);
C) all replications of days 2, 3 and 4 (3 replications);
D) the first replication of day1, and all of days 2, 3 and 4 (4 replications).

RESULTS AND DISCUSSION

Droplet size measurements

The results from the droplet size measurements (Figure 1) showed that for all the nozzle conditions used, the addition of the tracer dye did not alter the mean droplet size as expressed as a v.m.d. or the percentage of spray volume in small droplets. This agreed with results reported by Palladini (2000) who also found that the food dye (Brilliant Blue FDC-1) used as a tracer for spray deposit assessments did not alter the surface tension of water-based solution.

Airborne spray profiles measured in wind tunnel conditions

The mean and standard deviation for the vertical and horizontal airborne spray profiles, expressed as a percentage of nozzle output showed only small differences between the different methods of replication (Figures 2 and 3). For the vertical airborne profiles (Figure 2), there were no significant differences in the results for the XR and AI nozzles. For the DG 11002 nozzle, the paired measurements gave the highest airborne spray values at the 0.1 to 0.3 m heights, while for the TT nozzle differences were only significant at the 0.5 m height where the replication on different days gave the lowest value of spray drift. Results for the measured horizontal profiles were also very comparable over the different methods of replication (Figure 3). For the XR and DG nozzles, the paired measurements gave relatively high values particularly at the shorter downwind distances.

In general, it was concluded that:

- the 'Green S' dye was a suitable tracer for use in spray drift assessments since droplet size distributions were not altered by its addition to water or surfactant solutions;
- Two replicated measurements in sequence and on the same occasion was a satisfactory method to evaluate spray drift in wind tunnel tests although there is a small risk of producing different means when compared with experiments with more replications;
- the variability of measured airborne spray profiles is highest at the lower heights and smaller downwind distances from the nozzle;
- Wind tunnel studies are an appropriate way of obtaining relative measures of the risk of spray drift from boom sprayers.

ACKNOWLEDGMENTS

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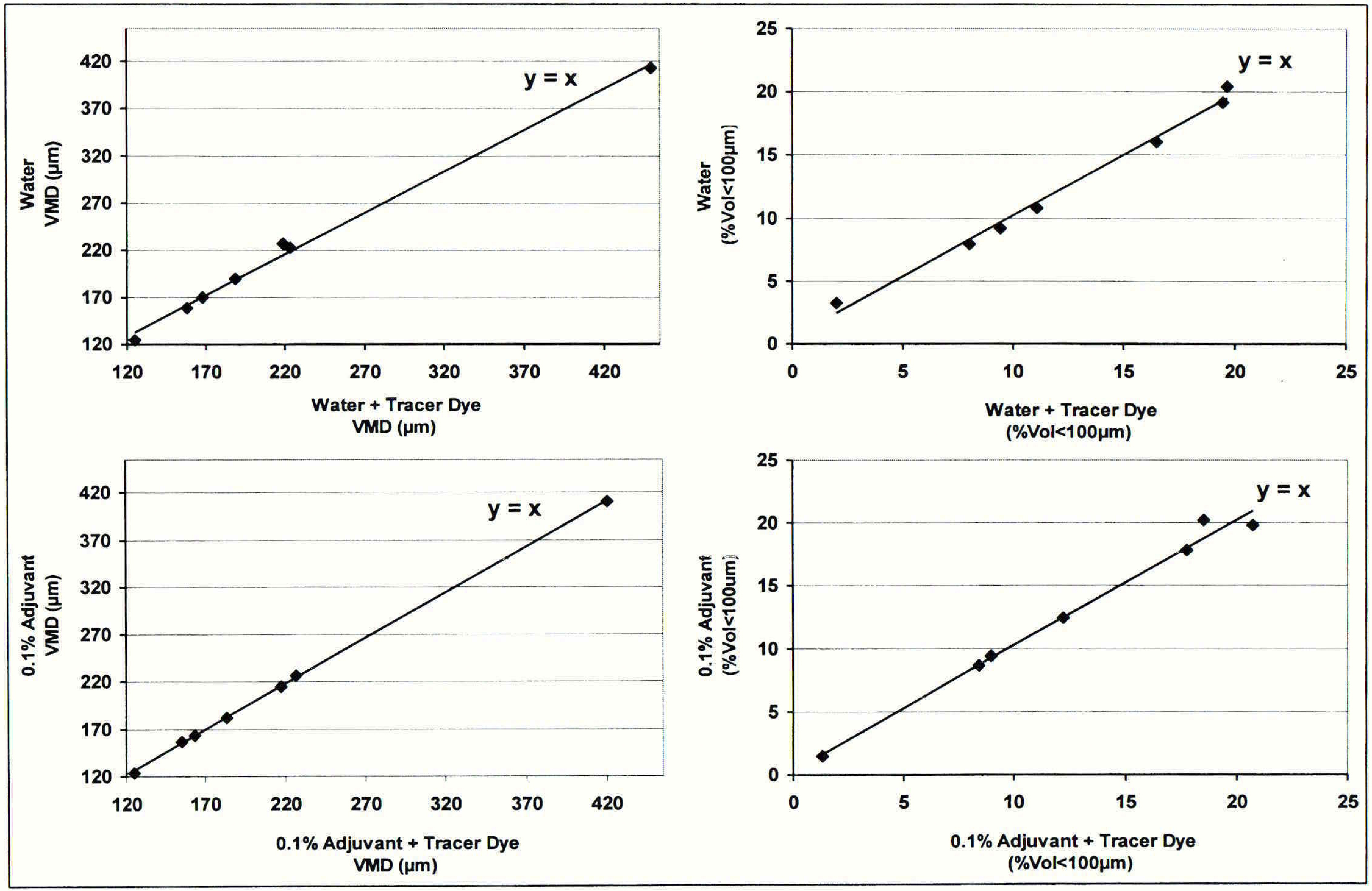

Figure 1. The effect on the droplet size distribution of adding the tracer dye to water and water plus adjuvant liquids

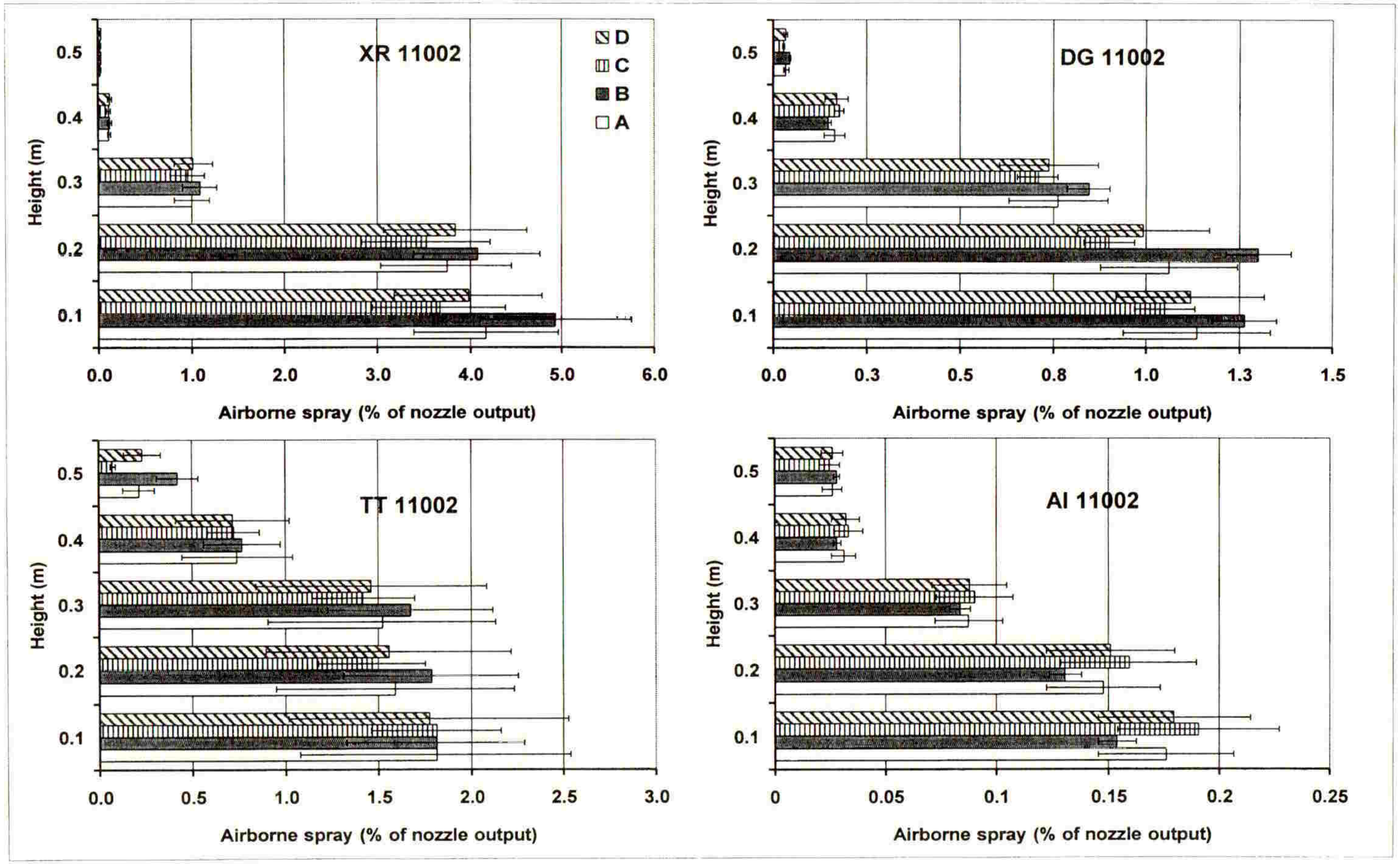

Figure 2. Repeat measurements of the vertical airborne spray profiles with the test nozzle conditions (XR11002 at 3.0 bar pressure)

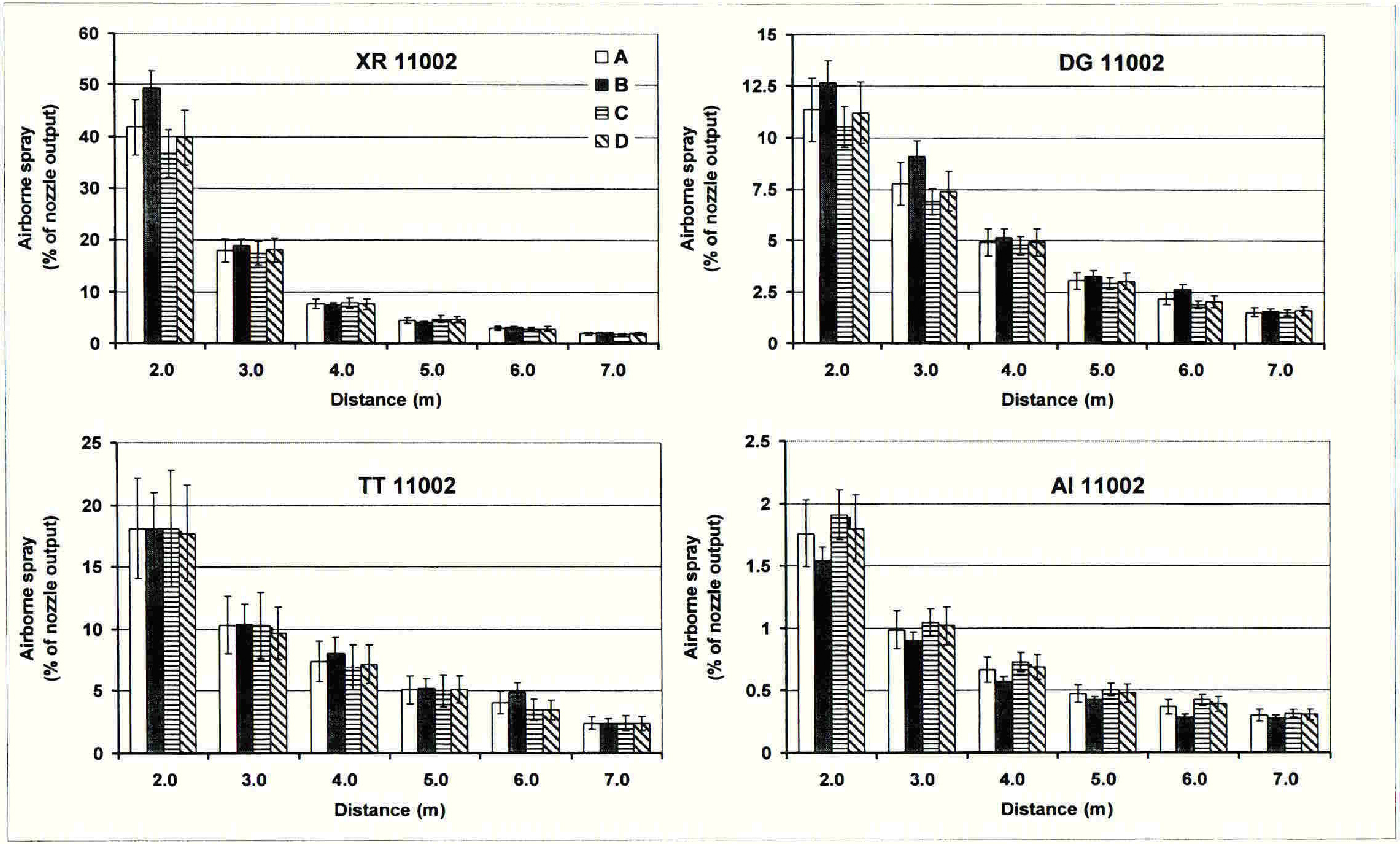

Figure 3. Repeat measurements of the horizontal airborne spray profiles with the test nozzle conditions (XR11002 at 3.0 bar pressure)

Air entrainment in sprays generated by different agricultural nozzle conditions

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ABSTRACT

Measurements of the air entrainment associated with different agricultural nozzle conditions were made by recording air velocities with the nozzles spraying into three sizes of a parallel plate arrangement. Results showed that for conventional flat fan nozzles, air entrainment increased with nozzle size and operating pressure as expected. For a given flow rate, hollow cone nozzles entrained approximately 40% more air than flat fan designs. Higher entrained air velocities were measured with the nozzle at the top of the plates and with the deepest plate section.

INTRODUCTION

Air entrainment is known to be an important parameter influencing droplet behavior within a spray, penetration into crop canopies and the risk of spray drift. A number of studies have therefore aimed at quantifying air entrainment conditions and relating such entrainment to nozzle operating conditions (Miller *et al.,* 1996). Entrained air velocities have been tracked experimentally by measuring the velocities of small droplets (<50 μm in diameter) using instruments such as the phase Doppler analyser. Work has also sought to utilize the air entrained within a spray (Miller & Hobson, 1991) as an alternative to air assistance provided, for example, by an inflated air duct mounted on a boom.

The work described in this paper aimed at quantifying entrained air velocities for a range of nozzle conditions by mounting nozzles to spray into a pair of shaped plates similar to those used by Miller & Hobson (1991) and measuring the air flow into the plates.

MATERIAL AND METHODS

Three pairs of shaped plates were made from aluminum sheet by rolling a semi-circular upper section of 50 mm diameter such that when mounted together, a curved inlet to a parallel plate arrangement was formed with three different depths measured from the bottom of the curved inlet section. Plates with depths of 100 (shallow), 150 (medium) and 200 (deep) mm were formed. The plates were supported such that they were parallel over the 2.0 m length and the distance between plated could be varied. Three spray nozzles at 0.5 m spacing were mounted between the plates in a way that allowed the position relative to the top (or bottom) of the sheets to be varied. Nozzles were supplied with water from a pressurized container with the pressure at the nozzle measured by an electronic transducer. Pressure at the nozzle was adjusted by varying the air pressure supplied to the container.

Air velocity into the plates was measured at distances up to 250 mm either side of the nozzle position in 50 mm increments along both sides of the pair of plates. Two repeat measurements were made at each position giving a total of 20 air velocity measurements for each nozzle/plate configuration studied. Measurements were made using a hand-held hot wire anemometer. Care was taken to align the sensing head of the anemometer with the direction giving the highest air velocity and to avoid the measurement head coming into contact with spray droplets. The instrument was connected to a hand-held data logger and set such that each recorded data point was a mean of 20 values taken at 2.0 s intervals. Values were then averaged to give mean air velocities at defined distances from the nozzle position.

Measurements were made with a range of nozzle sizes, types and operating pressures spraying into different plate arrangements achieved by using the three sizes of plate, a different spacing between the plates and within different nozzle positions with the plates.

RESULTS

For all cases studied, entrained air velocities were highest closest to the nozzle as expected. Measured velocities were reasonably consistent and repeatable over the three days that the experiments were conducted.

The effect of nozzle size and pressure

Increasing the size of conventional flat fan nozzles increased the velocities of the entrained air as expected (Figure 1). All measurements were made when spraying at a pressure of 3.0 bar, using the medium size plates spaced 55 mm apart and with the nozzles positioned 40 mm from the base of the plates. Peak velocities close to the nozzle were more than 50% higher than values measured between nozzles, with the form of the velocity/distance profile being reasonably consistent for all the nozzle sizes examined. The largest measured increase in entrained air velocities was between nozzles having a flow rate of 1.6 (FF110/1.6/3.0 – "04") and 2.4 (FF110/2.4/3.0 – "06") litres/min.

Increasing pressure also increased entrained air velocities as expected (Figure 2). Measurements were made with the same plate configuration as for the data in Figure 1 – medium plates spaced at 55 mm and with the nozzle mounted 40 mm from the base of the plates. Mean velocities for all measuring points showed the expected trend except for the FF110/1.6/3.0 nozzle at a pressure of 4.0 bar were measured values had fallen below those of the smaller nozzle sizes. Again the most pronounced change in entrained air conditions was between the FF110/1.6/3.0 ("04") and FF110/2.4/3.0 ("06") nozzles.

The effect of nozzle type

Measurements with a conventional hydraulic flat fan pressure nozzle, a hollow nozzle and a pre-orifice flat fan nozzle showed that the highest entrained air velocities were achieved with the hollow cone design (Figure 3). Measurements were again made with the plate configuration used to produce the data in Figures 1 and 2.

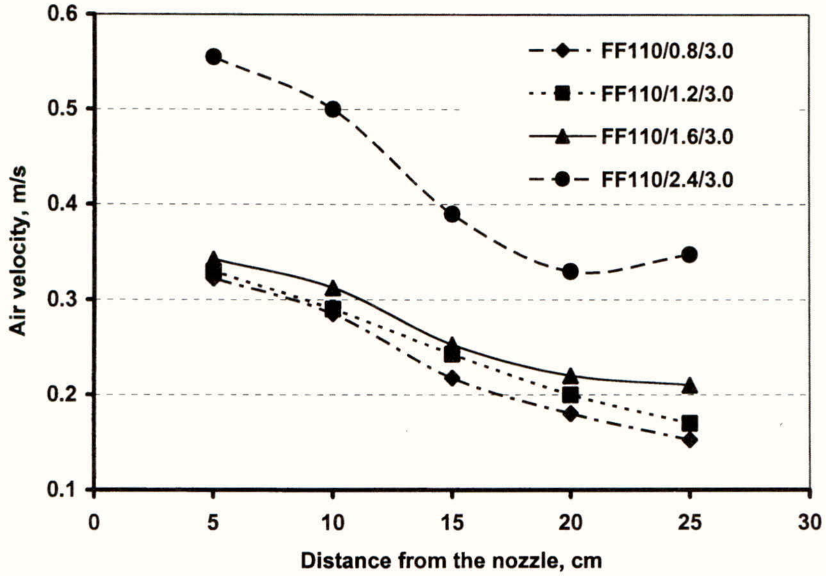

Figure 1. The effect of nozzle size on measured entrained air velocities with flat fan nozzles

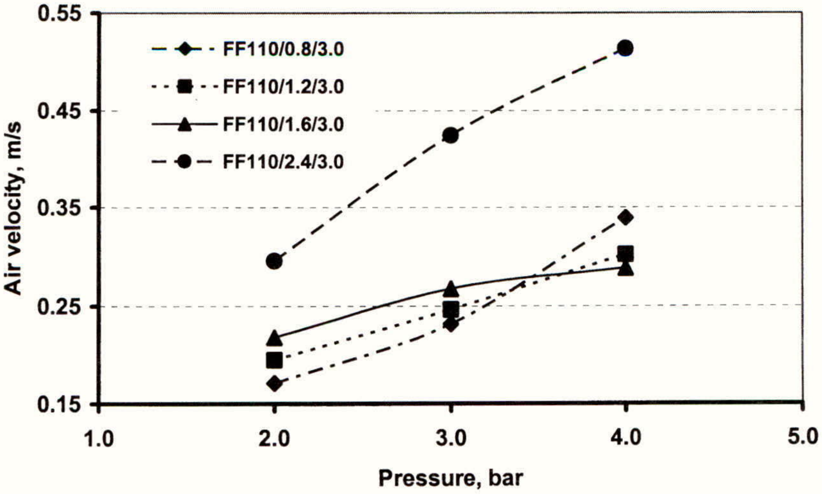

Figure 2. The effect of pressure on entrained air velocities with different sizes of flat fan nozzle

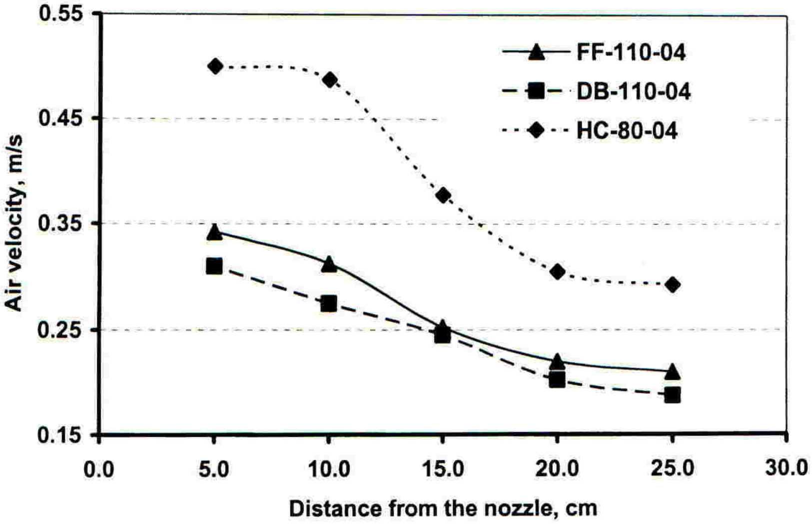

Figure 3. Entrained air velocities measured with different nozzle types operating with a flow of 1.6 litres/min

Measurements of the droplet velocities in the sprays from different designs of agricultural nozzle have shown that the highest velocities are associated with conventional flat fan nozzles. This might then suggest that the highest entrained air velocities would be found with this nozzle design. However, the spray from the hollow cone nozzle has a much greater area in which to entrain air. This was noticeable in the experiments reported here since the plate arrangements had generally been selected to minimize the contact of spray onto the plates. With the hollow cone nozzle there was substantial wetting of the plates with spray running down and dripping from the bottom of the plates. The results indicate that the area occupied by the spray is an important factor influencing the quantity of air entrained into the spray. The geometry of the sprays produced by the conventional flat fan and the pre-orifice nozzles were very comparable and the lower entrained air velocities with the pre-orifice design were therefore probably a function of the lower droplet velocities at the output from this type of nozzle.

The effect of nozzle position between the plates

The results shown in Figure 1 to 3 had all been obtained with the tip of the nozzle mounted 40 mm from the base of the plates and with much of the nozzle body positioned between the plates. The size of the nozzle body and mounting cap had limited the minimum spacing between plates that could be used to 55 mm. In practice it was recognized that positioning plates closer together than this substantially increased the risk of the plates intercepting some spray with this running down and dripping from the base of the plates. Raising the nozzle within the plates was found to substantially increase the velocities of the entrained air. Measurements with a conventional 110 degree flat fan nozzle operating at a pressure of 3.0 bar and with a flow of 1.6 litres/min (Figure 4) showed that entrained air velocities close to the nozzle position could be increased by a factor of more than 2.5 times by raising the nozzle position from 40 mm from the base of the plates to140 mm from the base of the plates when using the medium depth plates.

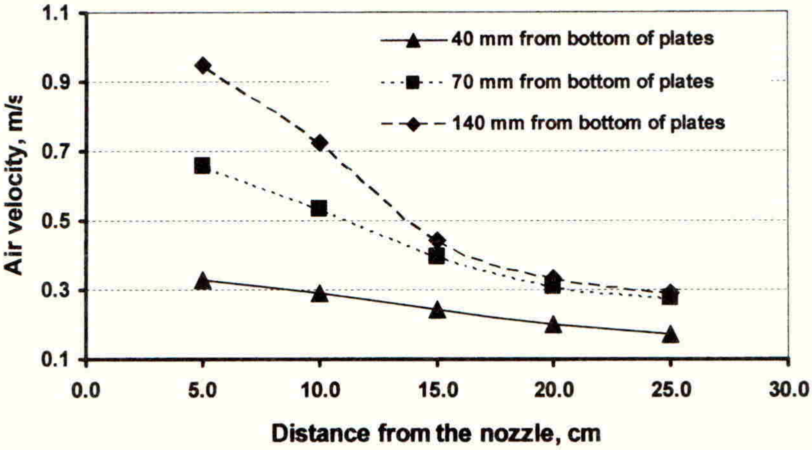

Figure 4. The effect of nozzle position between the plates

The effect of different plate depths

Increasing the depth of the plates was shown to consistently increase the entrained air velocities when measured with a conventional 110 degree flat fan nozzle operating at a pressure of 3.0 bar and with a flow of 1.6 litres/min (Figure 5). The range of plate depths chosen for this work was based on sizes that could be used practically on a boom (Miller & Hobson, 1991). Increasing the plate depth was expected to give improved air flow conditions around the spray but with higher friction of the air against the plates. The measured result suggests that the effect of air friction on the plates is almost negligible. When mounted on a boom, the presence of plates of the sizes used in these experiments would influence air and spray behaviour although the results of wind tunnel and field experiments reported by Murphy *et al.* (2000) suggests that these effects would be small.

DISCUSSION

The results of the work reported here indicated that comparative measures of the quantity of air entrained in spray with different agricultural nozzles could be obtained by the techniques used. Air velocities were relatively low when compared with those used on air-assisted boom sprayers and may not be sufficiently large to change spray behaviour in a way that would justify the cost and complexity of engineering in a practical design.

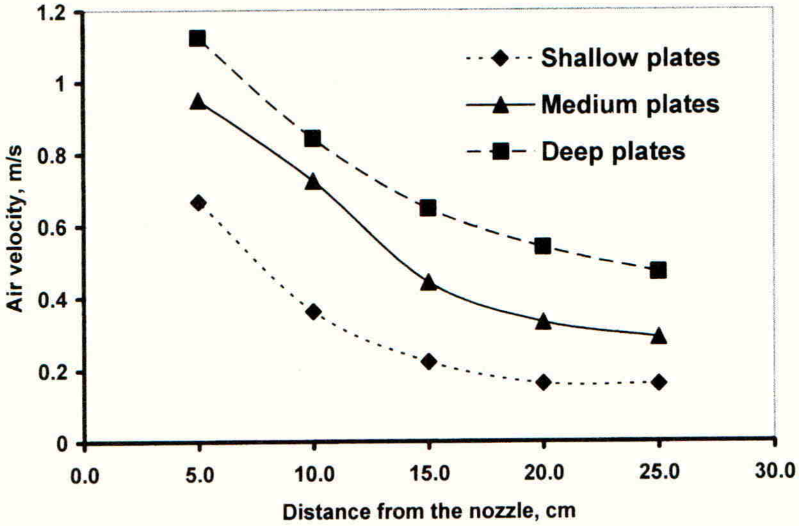

Figure 5. The effect of changing the depth of plates

The approaches taken in the study were relatively simplistic. There is scope for more detailed work using, for example, computational fluid dynamics techniques to quantify the flow conditions and extend the measured variables to a wider range of conditions. However, such studies are only justified if there is a way in which the results can be practically exploited. Understanding the role that entrained air can play in influencing spray movement is important but the results from this work suggest field trials need to be conducted to determine whether there is a practical benefit from utilizing the effects relating to such flows.

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The low volume application of herbicides

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ABSTRACT

Experimental investigations of the effect of reducing application volumes from 100 down to 37 litres/ha were made on the performance of the herbicide tralkoxydim on Italian ryegrass. Two nozzle types were used, conventional flat fans and air induction nozzles. In addition, the effect of angling nozzles backwards was evaluated. Results showed no statistically significant effect of application volume or nozzle angle on the either the efficacy of the herbicide or the quantity deposited. There was also no effect of nozzle type on efficacy, although there was a difference in the quantity deposited. The results suggest that wind effects are an important variable influencing spray deposition.

INTRODUCTION

Reducing water volume rates is one of the most useful methods of increasing work rates, thereby improving the timeliness of the application. This can contribute significantly to maximising the efficacy of the pesticide, leading to lower inputs. The survey of UK farm sprayer practices (Garthwaite, 2002) suggested that in 2000, around 30% of the arable area was sprayed at volumes lower than 150 litres/ha and this reduction in application volume is seen as a growing trend.

In practice, there have been two limiting factors preventing volumes from being reduced: spray drift and a lack of reliable data concerning efficacy. While spray drift can be overcome by developments in application techniques, maintaining efficacy is more difficult since it depends upon a range of factors. For any given pesticide and dose, there may be a limit below which application volume cannot be reduced without compromising the quantity of pesticide retained and the distribution of deposits on the target. This limit may depend upon the application equipment and operating parameters. Experimental evidence of the effect of application on pesticide performance is not always consistent, (e.g. Knoche, 1994) probably because there are a number of interacting factors, including parameters relating to the application, crop and the pesticide product.

A series of laboratory experiments were undertaken to investigate the implications of reducing volumes for spray characteristics (Butler Ellis *et al.*, 2003). While there were some slight changes in the quantities deposited on small vertical artificial targets (chosen to represent the geometry of small grass weeds) as volumes reduced, the major changes were in reductions in coverage at low volumes and with large-droplet air induction nozzles and higher variability in levels of deposit with large-droplet air induction nozzles at all volumes.

It is hypothesised, therefore, that pesticides that need good coverage will perform better with higher volumes and worse with large-droplet air induction nozzles. In addition, the variability of quantity deposited on small targets by large-droplet air induction nozzles may lead to poorer performance for some pesticide applications.

The aim of the work reported in this paper was to test the performance of a pesticide on a small spray target i.e. herbicide applied to small grass weeds, which may be susceptible to both poor coverage and variability in deposit. Previous work (Powell *et al.*, 2002) demonstrated that black-grass control was compromised by the use of large droplet air induction nozzles at 100 litres/ha, suggesting that coverage and/or variability may be important. Since coverage in particular declines with application volume, differences in performance between application systems might be exaggerated at volumes lower than 100 litres/ha. The aim was therefore to identify the volume at which herbicide performance begins to decline and to determine whether this threshold volume is dependent on application technique, in particular the use of drift-reducing nozzles.

The effect of angling nozzles was also investigated, since purpose-designed angled nozzles for grass weed control are becoming commercially available and previous laboratory measurements (Butler Ellis *et al.*, 2003) suggested that angling nozzles may improve deposits on small vertical targets, particularly with some nozzle designs and at low volumes. Herbicide efficacy was investigated over two seasons, and a separate trial was done using the same application techniques to evaluate deposits on small grass weeds.

MATERIAL AND METHODS

Field trials were carried out in two successive seasons, 2002/03 and 2003/04. In order to ensure a uniform, susceptible weed population, plots of winter wheat drilled in mid October were under-sown with Italian ryegrass at a rate of 6 kg/ha. This produced an average pre-treatment ryegrass population of about 180 plants/m^2 in 2002/03, but only 50 plants/m^2 in 2003/04 as a result of the drier autumn.

Efficacy trials

Eight spray treatments were applied with a Hardi Master MB800 to plots measuring 5.0 m wide and 20.0 m long, and replicated four times. An additional area was left untreated. The herbicide used was the foliar-acting product tralkoxydim ('Grasp', Syngenta Crop Protection UK Ltd.) at a rate of 0.7 litres/ha, applied with the adjuvant 'Output' (Syngenta Crop Protection UK Ltd.) at a fixed dose of 0.36 litres/ha. Application dates (and ryegrass growth stages) were 12/2/03 (GS13-15) in 2002/03 and 15/12/03 (GS12) in 2003/04.

Control of ryegrass was evaluated 2 months after application, on 16/04/03 and 18/02/04 respectively. This was achieved by counting the number of weeds that had survived treatment in five 0.10 m^2 quadrats per plot. These had been marked and counted prior to application. The percentage control in each quadrat was then calculated and an average taken. Further assessments of the ryegrass population were carried out at 3 months after application and at heading, but these were considered less reliable due to the difficulty by that stage in differentiating plants that had emerged after the treatment application.

Table 1. Treatments for the efficacy trials

Application volume, litres/ha	Speed, km/h	Nozzle type/ size	Pressure, bar	Angle
164	8.0	FF/110/1.2/3.0 (03)	2.5	Vertical
164	8.0	Air induction Drift Beta (03)	2.5	Vertical
73	8.0	FF/110/0.6/3.0 (015)	2.0	Vertical
73	8.0	Air induction Drift Beta (015)	2.0	Vertical
37	16.0	FF/110/0.6/3.0 (015)	2.0	Vertical
37	16.0	Air induction Drift Beta (015)	2.0	Vertical
73	8.0	FF/110/0.6/3.0 (015)	2.0	30 degrees backwards
73	8.0	Air induction Drift Beta (015)	2.0	30 degrees backwards

Deposit trial

The spray liquid used was 0.1% 'Agral' (Syngenta Crop Protection UK Ltd.) with 1.0 g/litre 'Green S' (Merck Chemicals) tracer dye. While there is likely to have been differences in spray liquid properties between this test liquid and the tank mix containing the herbicide and adjuvant, and this might lead to differences in retention on ryegrass plants, these differences are likely to be small (Butler Ellis *et al*., 2004). The relative levels of spray deposit for different application techniques are expected to be similar. Applications were made with a 1000 litre, 12 m mounted air assisted sprayer but without the air assistance being used and the air bag tied down to the boom to minimise the disturbance to air flow around the boom. Wind speeds at a height of 2.0 m at the time of application were measured with a vane anemometer.

The same treatments as for the 2002/3 and 2003/4 efficacy trials were evaluated, with three replicate plots per treatment. Following spraying, five samples of 10 plants were taken randomly from each plot and washed in de-ionised water. The washed-off solution was analysed by spectrophotometry and compared with a tank sample to determine the quantity of spray liquid retained.

In addition to the direct sampling of plants, 50 mm wide strips of chromatography paper were mounted on wooden lathes and laid in line with crop rows at the edge of each plot. These strips enabled spray deposits to be visualised for each plot treatment and strips from replicated plots were collected together and photographed to give a record of the treatments applied.

RESULTS AND DISCUSSION

Efficacy trials

Results for the 2002 and 2003 trials (Table 2) showed that there were no statistically significant differences in 2002/3, and only between the best and the worst in 2003/4. No trends in terms of application volume or application type were apparent.

Table 2. Percent weed control for the 2002 and 2003 trials, measured two months after application

Application volume, litres/ha	Speed, km/h	Nozzle type/ size	Angle	% Control 2002	% Control 2003
164	8.0	Flat fan	Vertical	70	89
164	8.0	Air induction	Vertical	77	92
73	8.0	Flat fan	Vertical	69	83
73	8.0	Air induction	Vertical	70	98
37	16.0	Flat fan	Vertical	80	95
37	16.0	Air induction	Vertical	75	97
73	8.0	Flat fan	30 degrees backwards	65	80
73	8.0	Air induction	30 degrees backwards	68	90
Least significant difference				23	16

Angling nozzles 30 degrees backwards also had no statistically significant effect on performance, although the angled treatments were consistently poorer than the vertical treatments. There is therefore no evidence to support the hypothesis that backward-angled nozzles improve control of small grass weeds.

Deposit trial

Measurements of the quantity of spray liquid deposited on ten ryegrass plants are shown in Figure 1. During application of the 73 litres/ha angled treatments on two plots (one flat fan and one air induction), a gust of wind was measured of more than 3.5 m/s compared with mean speeds for most of the applications that were between 2.0 and 2.6 m/s. When the deposit data was analysed, it was apparent that this had an important effect on deposit and was therefore removed from the results shown in Figure 1. An analysis of variance of all data showed that there is a statistically significant interaction between gust and nozzle ($F(2,11) = 17.4$, $p<0.001$) and there were no other statistically significant treatment effects or interactions. The interpretation of this interaction may relate to the gust of wind having a greater effect on the spray from the flat fan nozzle compared with that from the air induction nozzle. In both cases, the deposition was increased but for the air induction nozzle, the response was 1.4 times greater whereas for the flat fan nozzle, the response was 2.6 times greater. Similarly, the difference between the flat fan and air induction nozzles was dependent on the wind speed – i.e. the flat fan nozzle produced deposits 1.6 times that of the air induction nozzle without the gust, but 2.8 times greater when there was a gust.

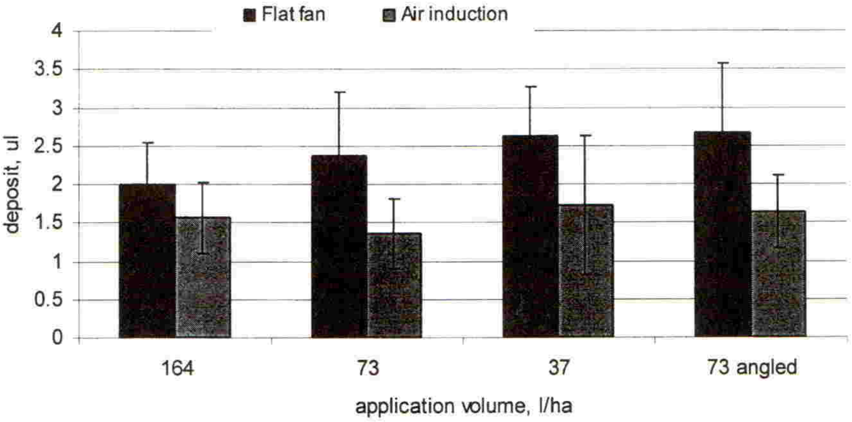

Figure 1. The effect of application volume and nozzle type on the deposit on 10 ryegrass plants.

Although there is an apparent increase in deposit as volume reduces with a flat fan nozzle, this was not statistically significant. This is consistent with laboratory results, (Butler Ellis *et al.*, 2003) where in two separate experiments, one showed no effect of reducing volume, and the other an increase in deposit. It was hypothesised that under more natural conditions, something between the two, i.e. a small volume effect might occur. This is due to the ability of a fine spray to take advantage of air currents that will provide horizontal trajectories and increase the probability of making contact with vertical targets. The spray from the air induction nozzle, since it is relatively unaffected by air currents (and hence controls drift) would not be deflected from its original trajectory, leading to lower deposit levels.

The variability of deposit on individual plants could not be determined because insufficient quantity retained on such small plants would lead to poor resolution. However, coefficients of variation for 10 plants (Table 3) showed that for flat fan nozzles there was again no volume effect while for air induction nozzles, there was a noticeably higher CV at 37 litres/ha, suggesting that the lowest volume treatment with the air induction nozzle might result in poorer levels of control on some plants.

Despite this, results from the first two seasons showed no effect of either nozzle or volume. The mean wind speed during the deposit trial was around 2.2 m/s. It is possible that, in lower wind conditions, there would have been lower deposit levels from the flat fan nozzle and therefore much smaller differences. Previous laboratory measurements in still air showed no difference between conventional flat fan nozzles and air induction nozzles with artificial targets (Butler Ellis *et al.,* 2003). However, unpublished laboratory measurements with ryegrass plants, although not statistically significant, also suggested lower retention with an air induction nozzle producing very large droplets. It would be interesting to establish whether the deposit from an air induction nozzle used in "windy" conditions would be equivalent to the deposit from a flat fan nozzle used in "ideal" conditions.

Table 3. Coefficients of variation of deposit on ryegrass plants

Application volume, l/ha	Flat fan	Air Induction
164	26.51	29.53
73	34.52	33.72
37	24.41	52.02
73 - angled	34.31	28.81
Mean	29.94	36.02

CONCLUSIONS

There was no effect of volume on the performance of the grass weed herbicide tralkoxydim on ryegrass, nor was there any effect of nozzle type, when comparing conventional flat fan nozzles with an air induction nozzle. Angling nozzles backwards at 30 degrees also had no effect on performance.

Measurements of deposit on ryegrass plants showed that there is a possibility of a difference in deposit between flat fan and air induction nozzles but this depends on the wind speed at the time of the experiment. Flat fan nozzles produce a fine spray that can be influenced by air movements that potentially increase the deposit on small vertical targets. The use of the flat fan nozzle resulted in deposits that were significantly higher than those from an air induction nozzle, and the difference increased as the wind strength increased. Spraying during "ideal" low wind speed conditions would be likely to reduce the difference between the two nozzle types.

Since no differences in control were observed in any of the field trials, it is likely that any differences in the quantity deposited on ryegrass plants were too small to have any effect.

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The performance of automatic spray application recording devices

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ABSTRACT

Trials undertaken with a 12 m sprayer fitted with an automatic record creation capability indicated that during steady state spraying, recorded applications closely matched deposits measured on a flat target. This indicated that records accurately reflected actual applications. However, during the transition from high to low rates when using conventional flat fan nozzles, delays in spray hitting the target probably due to aerodynamic effects meant that for a distance of 4.0 metres, records varied significantly from actual application. When fitted with air induction nozzles creating a larger droplet size and with less aerodynamic disturbance, no discrepancy between recorded and measured applications was observed.

INTRODUCTION

Traceability is an important aspect of agricultural production (Anon., 2002). Recent EU regulation will require more detailed information about how crops are grown to be available further down the food chain to ensure that, in the event of food related health issues, the source and extent of the problem can be determined. Traceability is reliant on robust and accurate methods of recording that on the farm is currently a manual process and can be prone to error.

Watts *et al.* (2004) described a device that, when installed near the induction hopper of a sprayer, allowed filling records to be automatically produced. Two methods of automatic identification of chemical products were considered, namely bar codes (Osman & Furness, 2000) and Radio Frequency Identifiers (RFID) (Pendrous, 2002). Although records relating to the amount of chemical loaded were shown to be within acceptable limits, experimental work was needed to determine how well automatically generated application maps compared with measured target deposits so as to assess the overall resolution and accuracy likely to be achieved using such systems.

MATERIALS AND METHODS

A 1000 litre 12 m fully mounted sprayer (Hardi 'Twin' system) attached to a conventional agricultural tractor was used. The tractor was fitted with items of non-standard equipment that included a pulsing wheel sensor that, when calibrated, allowed the determination of distance down the tramline and machine speed and a 10 channel GPS unit to allow determination of position within a field.

The sprayer was modified to allow it to create "as applied" maps on a laptop computer using the approach described by Watts *et al*., (2004). During loading and when spraying, flows into and out of the sprayer tank were monitored using oscillating piston flow meters. The pulsed output from all the sensors (water fill, spray flow and pulsed wheel sensor) were acquired by a data logger (Campbell 21x), with output via an RS232 link to a portable computer.

The experimental approach used in the work reported in this paper was based on recording the applied spray at ground level by capturing deposits on strips of chromatography paper mounted on the ground. Applications were made at a nominal 200 litres/ha using conventional flat fan and air induction nozzles mounted on opposite sides of the boom. Air induction nozzles, typically used for improved drift control when compared with conventional flat fan types, give larger droplet sizes that are potentially less influenced by external air flows such as wind and boom movements.

The length of sampling papers needed to be related to the response characteristics of the control valves on the sprayer. An initial experiment was therefore designed to determine the time taken for closing the main and boom valves. Measurements were made manually (using a stopwatch) and by measuring the flow from the boom using the flow meters under static conditions. Both the main valve and boom section valves were found to have shutting times of approximately 3.0 s after the average of 5 replicated measurements was taken. It was therefore concluded that with a forward speed of 2.0 m/s, approximately 10 m of strip would be required to monitor applied spray during shutoff, and thus a total strip length of 15 m was used.

Sample collection

The use of sampling papers placed in the area to be sprayed is a well-established procedure for determining drift potential and deposition from sprayers. A tracer dye ('Green S' – Merck Chemicals) was added to the spray tank contents at a concentration of 0.2%. After spraying, the target (e.g. chromatography paper) was then washed and the dye extracted into a specific volume of water. The resulting solution was then be analysed by spectrophotometer to determine the concentration and hence the total amount of dye that was collected from a known area.

In this experiment, 15 m strips of paper 50 mm wide were laid along a 25 m track (Figure 1). An initial 5 m of track was allowed for the tractor to attain steady state speed and pressure conditions. From this point a uniform application was made for the next 5 m (Figure 1). The booms were then switched off allowing 10 m (5 s) of paper to be sprayed whilst the sprayer output decayed to zero. With knowledge of tractor location relative to the strips on the ground it was possible to correlate recorded application with the measured deposits prior to, during and after valve closure.

After collection of the target strips, they were cut into 1.0 m segments and the tracer dye recovered from each segment in 1.6 litres of water. This provided a record of the average application rate at a rate of 2 records per second. The area of the cut strips was calculated and application rate determined based on the quantity of dye extracted. This was then compared with machine records.

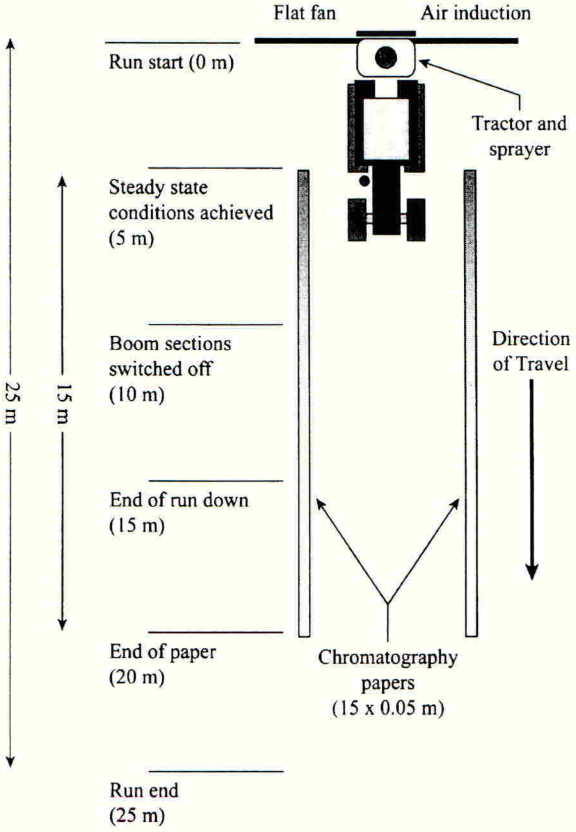

Figure 1. Experimental layout of driven course

RESULTS

Figures 2 and 3 show a comparison of the actual amount of tracer dye measured on the target paper with that recorded by the sprayer for low drift air induction (Figure 2) and conventional flat fan nozzles (Figure 3). Actual and machine recorded application rates for the air induction nozzles correlate well. With the sprayer operating in steady state at 8.0 km/h (2.2- m/s), the amount of tracer dye recorded agreed well with that measured at the target – see distances 5 – 10 m down the tramline on Figure 2. At the point where the boom sections were switched off (10 m down the tramline), the recorded application rate dropped sharply as expected. For the air induction nozzles there was a slight delay in the response, but during the transition between the high and low rate there is a good correlation between the recorded applications and measured deposits.

In contrast, although there is a good correlation between machine recorded rates and measured deposits during steady state for the flat fan nozzle (Figure 3), during the transition there is a delay of approximately 4 m where the application rate is significantly higher than measured deposits. This may be due to the aerodynamic effect of the air flow around the booms causing the spray to be deflected in the direction of the machine rather than being forced rapidly towards the target.

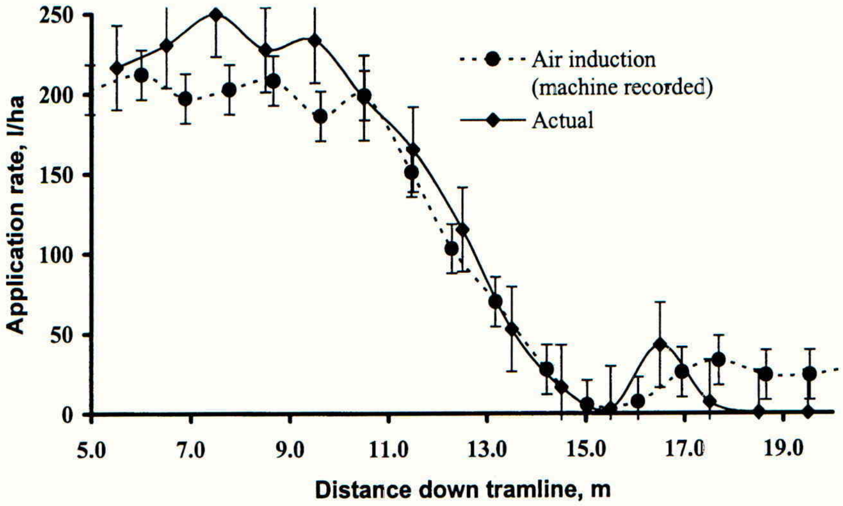

Figure 2. Machine recorded and actual application rates (air induction nozzles)

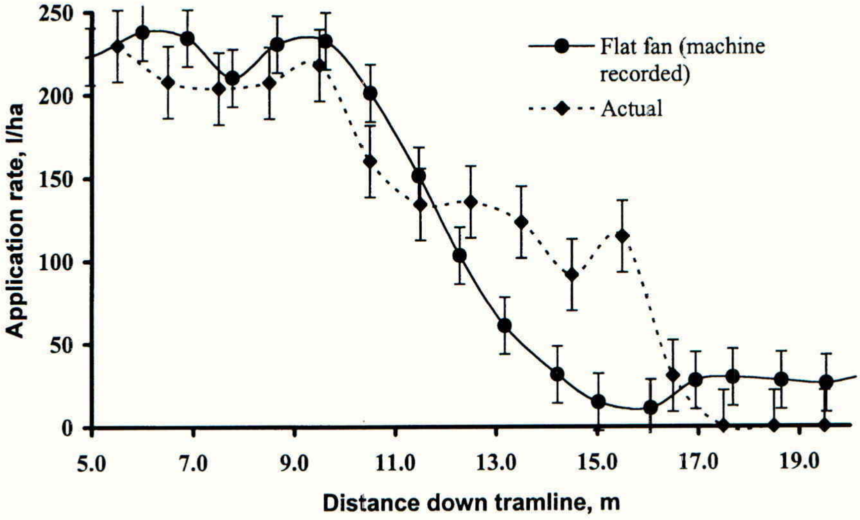

Figure 3. Machine recorded and actual application rates (flat fan nozzles)

The results show that the accuracy of the record can be influenced by nozzle type and/or droplet size together with prevailing weather conditions, and thus these must be compensated for if the machine record is to show a true representation of what chemical reached the target in a particular place.

DISCUSSION

Monitoring system performance

Although it is clear that there is the potential to automate the recording of farm operations to improve food chain traceability, it is essential that that information is correct. The experimental work, using agricultural spraying as an example, clearly showed that although the quality of recording was acceptable under steady state conditions, during the transition between high and low rates the recorded rate dropped much quicker than the actual rate leading to a variation between the actual and recorded application rates. This has implications at field headlands or where variable rate treatments are applied. It is thought this error occurs due to two main effects. These are:

(i) sprayer design - valve characteristics, valve location and pipe work design
(ii) aerodynamic effects - nozzle characteristics

Previous work undertaken indicates that there is scope for improvement in both these areas. Work by Paice *et al.* (1995) showed that without optimisation of the boom pipe work there would be differences in application rate along the boom. Correction of this using small bore piping to equalise/minimise dead volume, along with system modelling to design the pipe connections in a way that minimised pressure variations, resulted in improvements in the response to spray a defined target. Miller & Watt (1989) investigated the use of a solenoid valve to control the flow of the spray to the nozzle. Response times for conventional flat fan nozzles were found to be in the order of 100 ms, with predictable cut off characteristics. The current study, together with previous work, therefore indicates that with suitable sprayer modification, the monitoring of flow up to the point of the nozzle would be predictable.

It is clear from the results of the work reported here that some error is due to the time taken for spray, on exiting the nozzle, to hit the target. Although not quantified in this experiment, the use of two different nozzle types (air induction and flat fan) highlights that the less drift prone air induction nozzle has an improved fit with the recorded application than that of the flat fan. Work by Murphy *et al.* (2000) in a wind tunnel indicated that nozzle, boom type and nozzle height were all important factors controlling drift. Measures such as the use of air assistance to ensure a rapid transfer of spray from nozzle to target may also be helpful in making predictions about where spray hits the target. By quantifying such effects, there is the potential for including an offset in the machines recording system to compensate for the spray to target time.

The recorded error during a large transition between high and low spraying rates was 4 m. Work undertaken by Weitzein *et al.* (2003) on the static and dynamic accuracy of GPS devices indicated that Class 0 receivers working in open space could achieve an accuracy of 10 metres with selective availability turned off. GPS devices with differential correction (Classes 1 and 2) showed that 1 metre accuracy was possible. Accuracies for Class 3 and 4, (Dual frequency and RTK (Real Time Kinematic)) systems achieve sub-metre accuracy. The error therefore for the spray displacement is of similar magnitude to that achieved with GPS typically used on farms, and thus there is the potential to generate "as applied" maps with a resolution of better than 10 m accuracy.

CONCLUSIONS

Trials with a commercially available 12 m sprayer fitted with an automatic record generating system indicated that under steady state conditions records produced were within 10% of the chemical actually applied to the crop. During the transition between high and low application rates however, substantially greater variation between measured and recorded application rates existed for 4 m (2 s) at 8.0 km/h, with measured application rates being higher than recorded. Therefore the system is safe when rate is ramping up (because the response of the recording system is quicker than ground application) but potentially more erroneous on the ramp down (where the recording system records a value less than was actually applied). This variation is attributable to the design of the sprayer plumbing system and the aerodynamic effects of spray/boom interactions. Modelling and prediction of these effects could allow the correction of the recorded application rate so that it matched that measured on the ground. Errors associated with those of GPS and DGPS devices are of the same order of magnitude as those found with the spray displacement between nozzle and target. It is therefore likely that "as applied" maps could be generated with a 10m accuracy.

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