NOZZLES FOR MINIMISING AERIAL HERBICIDE SPRAY DRIFT

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ABSTRACT

Three nozzle types were compared in a trial investigating the potential for herbicide drift during aerial spraying. Water containing a colorimetric tracer, a fluorimetric tracer, and a foaming agent was sprayed from a helicopter boom along a single flight line. Deposition on steel plates located on the ground was measured to a distance of 300 m downwind. The airborne flux was measured to 225 m downwind, using "Rotorod" samplers. Conventional D8-45 nozzles were found to have greater drift potential than foaming nozzles (both pointing straight down). Lowest airborne drift occurred during use of D8 nozzles, pointing straight back. Deposition measurements using steel plates on the ground showed that peak deposition was greatest and closest to the flight line with D8 nozzles, followed by foaming and D8-45 nozzles. Steel plates on the ground were found to be unsuitable for estimation of airborne flux.

Keywords: aerial spraying; spray drift; herbicide; nozzles.

INTRODUCTION

Aerial spraying with herbicides is a common method of weed control during the establishment phase of *Pinus radiata* D.Don plantation forests. Broadcast aerial spraying makes it possible to efficiently control large-scale weed problems on inaccessible sites. However, concern over spray drift from herbicide applications continues to increase and this consideration often dictates the choice of spray application methods. In the 1970s, "foaming" nozzles were introduced into New Zealand. These are air-aspirated nozzles; air is drawn into and mixed with the spray liquid, which often includes a foaming agent, prior to emission from the nozzle orifice (Matthews 1979). It was claimed that foaming nozzles reduced drift (Clack 1972; Rowe & Albert 1976) and they quickly became widely accepted. Today they are still one of the most common nozzle types used to apply herbicides, in terms of hectares of forest land aerially sprayed.

Despite this popularity, there are no field data that compare spray drift from foaming nozzles with conventional disc and core, or other anti-drift nozzles. Furthermore, one laboratory study has suggested that there may be no advantage, in terms of drift reduction, of foaming nozzles compared to conventional nozzles (Bouse & Leerskov 1973). The objective of the trial described here was to compare the amount of spray drift from aerial

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applications of liquid when D8-45, foaming, or D8 (no swirl plate) nozzles were fitted on the spray boom. Currently, D8-45 and foaming nozzles are commonly used for forest herbicide spraying in New Zealand. The D8 nozzle type was selected for this trial because laser droplet size measurements (Yates *et al.* 1984) have shown that spraying water with a D8 nozzle at 0° produces a much smaller proportion of driveable droplets (i.e., those with diameters less than 150 μm) than the other nozzles.

METHODS

Trial Location and Sampling Scheme

The trial site was a flat, grass-covered area (approximately 350 × 450 m) at Tauranga airport. A single, 300-m-long flight line was orientated at approximately 90° to the mean wind direction. Spray was sampled along a transect laid at right-angles to the flight line and extending 50 m upwind and 300 m downwind from its mid-point (Fig. 1). Spray deposition was sampled using stainless steel plates (76 × 152 mm) placed horizontally on the ground at frequent intervals along the transect (2-m intervals within 20 m of the flightline, 5-m intervals between 20 and 100 m, and 50-m intervals between 100 and 300 m). Rotorod (rotating) samplers (Houle 1987), with easily removable 1.2-mm-diameter cylindrical stainless-steel catching surfaces, were placed 1.5 m above the ground at downwind distances of 35, 75, 150, and 225 m. The quantity of spray deposited on rotorods has been defined by Riley *et al.* (1989) as the flux of spray passing through a unit area in the vertical plane, the horizontal axis of which was parallel to the flight line. Collection of steel plate and rotorod samplers commenced 5 min after each application.

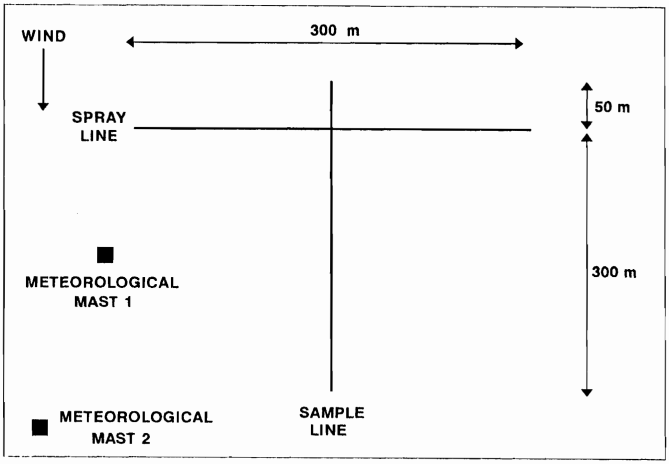

FIG. 1–Experimental layout at Tauranga airport.

Treatments

Measurements of deposition and airborne flux were made for each of the following three nozzle types:

- D8-45 disc and core (Spraying Systems Co.), pointing straight down (90°).
- Foaming nozzle (Delevan Co.) with a D6 disc, 90°.
- D8 disc (Spraying Systems Co.), pointing straight back (0°).

The time required to apply a set of replicated treatments increased the likelihood that meteorological conditions would change significantly during this period. Thus, the sequence of applications was chosen (1) to allow for comparisons against a standard treatment repeatedly applied throughout the duration of the trial, and (2) to minimise the time taken between treatments. The D8-45 treatment was selected as the standard. It was applied alternately with the other two treatments. The boom was fitted with two sets of nozzles, the D8-45 nozzles being fixed throughout the trial. After spraying the first D8-45 treatment, these nozzles were turned off and the other set was turned on for the application of the second treatment. This alternate sequence of treatment application continued throughout the trial. In total, six D8-45 treatments were applied. The first three were paired with three foaming nozzle treatments and the second three with three D8 treatments. Although this method would not yield a direct comparison of the foaming and D8 treatments if the meteorological conditions changed during the trial, it had the advantage that nozzles had to be changed only once (i.e., the foaming nozzles changed to D8). At all other times nozzles only had to be turned on or off.

Application Parameters and Deposit Assessment

The spray liquid was a mixture of water, a fluorimetric tracer (0.1 g pyranin/litre – Bayer NZ Ltd), a colorimetric tracer (10 g tartrazine/litre – Bayer NZ Ltd), and a foaming agent (0.44% "Delfoam" – Yates NZ Ltd.). Colorimetric and fluorimetric tracers allowed measurement of the deposit at two levels of resolution. Colorimetry is a rapid technique suitable for spray samples close to the flight line, where there is a high level of deposition. Fluorimetry is required for lower levels of spray deposit: pyranin had a reliable measurement limit of less than 1 ppb. Pre-trial tests were undertaken to determine whether the tracers would bind to the surface of collectors or if degradation from UV-radiation would be significant. Droplets of spray mix were placed on collecting surfaces using a micro-applicator. The spray material was washed from collectors that had been placed in the dark or sunlight for different time intervals, including periods in excess of that likely to occur during field tests, and the amount of dye recovered was quantified. These tests demonstrated that both tracers could be recovered with 100% efficiency (i.e., they did not bind to the surface of the collectors) and that pyranin degradation by UV-radiation was negligible (less than 5%) under conditions used during the trial.

Analysis of all samples was completed within 2 days of the trial. Spray deposits per unit area on the two types of sampler were quantified using standard colorimetric and fluorimetric techniques (Richardson *et al.* 1989). Where there were high levels of deposition, the light absorbance of the sample was measured at λ (wavelength) max. 435 nm using a spectrophotometer (Philips PU 8620). Elsewhere, pyranin was quantified using a fluorimeter (Perkin-Elmer Model 204-S) with λ max. excitation 403 nm and λ max. emission 506 nm.

All applications were made on 7 June 1991 from a Bell 206 Jet Ranger fitted with a flow meter and Simplex spraying system. Spraying pressure was 207 kPa for all applications. Each nozzle had a check valve, and nozzles were evenly spaced along the boom with the number of each type adjusted to give the required emission rate of approximately 270 g of spray material per metre of flight. Boom length (8.1 m) was 80% of the rotor diameter. A calibration check using the spray mixture was performed before each application. Each application consisted of three consecutive passes along the flightline, in a racetrack pattern, at 2-min intervals. After each application, the quantity of spray applied was noted and two samples of spray were taken from the boom to be used as standards in subsequent analyses. The pilot was instructed to fly at a boom height of 10 m above the ground and a ground speed of 83 km/h. Actual flying height and aircraft position at the mid-point of the flight line were measured using photography and triangulation. Actual aircraft ground speed was measured using speed-monitoring radar (Model KR-10SP, Kustom Electronics, 8320 Nieman Rd, Lenexa, Kansas, United States).

Droplet spectra for spray produced by each nozzle type were measured using a Malvern 2600 Particle Sizer in an open circuit wind tunnel (SpraySearch, Food Research Institute, Sneydes Road, Werribee, Victoria 3030, Australia), using the spray mixture (i.e., including Delfoam and dyes), appropriate orientation for each nozzle, and an airspeed of 83 km/h. There were difficulties in obtaining a droplet spectrum for the D8 treatment because of insufficient atomisation at the point of measurement. A droplet spectrum for this treatment was therefore taken from published measurements based on a different laser-imaging system (Particle Measurement Systems Inc.) using the same nozzle, nozzle orientation, and airspeed as in the trial, but water only and a higher spraying pressure (276 kPa as opposed to 207 kPa) (Yates *et al.* 1984).

Meteorological Measurements

Two 10-m-high meteorological masts were erected in the trial area (Fig. 1). On each mast a wind direction recorder (Skye Instruments) was installed at 5 m and cup anemometers (Casella and Skye Instruments) at 1.5, 5, and 10 m. Wet and dry bulb thermometers (Skye Instruments) were placed at 2.5 and 10 m on one mast only. Windspeeds (average wind-run over 1 min), temperature, humidity, and wind direction were recorded at the time of each spray run. Wind direction was recorded in 22.5° increments with an averaging time of 30 s. Mean and standard deviation wind directions during each treatment were calculated as a mean of eight readings.

Data Analysis

One-way analysis of variance was used to test for differences among treatments in terms of meteorological conditions (windspeed, wind direction, temperature, and humidity).

All deposit data from steel plates and rotorods were normalised to account for slight differences in application rates, and all subsequent analyses were based on the adjusted data. Deposition data on steel plates were averaged for each nozzle type and compared graphically. After a natural logarithm transformation to stabilise the variance, differences between treatment means were assessed at specific points downwind of the flightline (20, 50, 100, 150, 200, 250, and 300 m) using Fisher's Protected Least Significant Difference (FPLSD). These points were selected to include data close to the point of maximum deposition (i.e., within the effective swath of the aircraft) as well as long-distance drift.

Airborne flux data from the rotorods were also compared graphically and statistically. A square root transformation was the best method for homogenising the variance in airborne flux. All data were combined for a split-plot analysis of variance with the sampling position (distance downwind) nested within each nozzle replicate. Differences in airborne flux between each nozzle type were compared using orthogonal contrasts.

For both analyses, flying height, flying speed, windspeed, temperature, and humidity were all tested as possible covariates.

RESULTS

Meteorological Conditions

Meteorological conditions throughout the trial (Table 1) were remarkably consistent. The sky was virtually cloud-free, and a strong south-easterly wind varied little in direction and strength throughout the day (no significant differences among treatments; $p > 0.05$). Although the mean windspeed was higher than would normally be considered appropriate for herbicide spraying, it was ideal for determining the relative drift potential among the three nozzle types. There was a small but statistically significant increase in temperature and decrease in humidity over the duration of the trial ($p < 0.01$). The low humidities experienced throughout the day indicated conditions conducive to high evaporation rates, although this was somewhat offset by cool temperatures. The stability ratio, a simple ratio of temperature difference at two heights to windspeed, was small and negative or close to zero throughout the trial, indicating slightly unstable or neutral atmospheric mixing conditions (Quantick 1985).

TABLE 1–Summary of mean meteorological conditions, averaged over three runs per treatment

Treatment	Windspeed at 10 m (m/s)	Wind direction	Temperature at 10 m (°C)	RH (%) at 10 m	Stability ratio
A, D8-45	4.1	SE	12.2	53.5	–0.4
B, Foaming	6.4	SSE	12.5	51.5	–0.1
C, D8-45	7.0	SE	12.7	51.9	–0.2
D, Foaming	4.1	SSE	12.9	51.2	–0.1
E, D8-45	6.4	SE	13.4	50.7	–0.2
F, Foaming	5.4	SE	13.7	50.7	–0.2
G, D8	4.9	SE	14.1	49.6	–0.2
H, D8-45	4.7	SE	14.2	50.2	–0.2
I, D8	6.3	SE	14.3	46.9	–0.1
J, D8-45	6.2	ESE	14.3	47.8	0.0
K, D8	6.3	SE	14.3	47.6	0.0
L, D8-45	6.3	SE	14.3	49.1	0.0

Application Parameters

Despite the high windspeeds, the helicopter was flown accurately throughout the trial (Table 2). Mean boom height was 10.1 m (requested height of 10 m), mean flight line offset was 0.26 m, and mean flying speed was 82.5 km/h (requested speed of 83 km/h). There were no statistically significant differences among treatments with respect to flying height ($p=0.06$) although the trend indicated a slight increase in release height as the day progressed. However, there was a small but significant ($p=0.04$) increase in flying speed with the D8 treatments and the associated D8-45 treatments.

Droplet spectra produced by the three nozzles are indicated in Fig. 2, with droplet size plotted against the percentage of total spray volume (i.e., cumulative volume) contained within droplets of a size less than or equal to any specified diameter. The droplet size that divides a representative sample of droplets into two equal parts by volume (cumulative volume of 50%) is called the volume median diameter (VMD), and this parameter is often

TABLE 2–Summary of mean application parameters

Boom height (m)			Offset distance* (m)			Flying speed (km/h)		
Mean	Range	S.E.†	Mean	Range	S.E.	Mean	Range	S.E.
10.1	9.1–11.9	0.09	0.26	-0.6–0.9	0.06	82.5	77–87	0.41

* Positive is to the right of the flight line (i.e., downwind) when viewed from behind
† Standard error

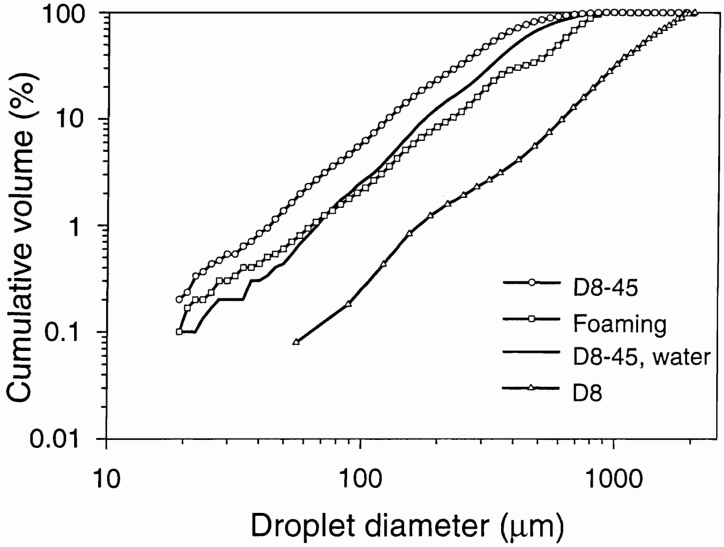

FIG. 2–Percentage total spray volume contained within droplets of a size less than or equal to any specified diameter; unless otherwise specified, spectra are based on the trial spray mix.

used to characterise a droplet spectrum. The D8 treatment produced the largest VMD (1246 µm), followed by the foaming nozzle (591 µm) and the D8-45 (314 µm). Of more importance in terms of drift potential is the proportion of spray volume in "driftable" droplets, generally considered to be those with diameters less than 150 µm. By this criterion, the D8 nozzle performed much better than the other two, with only 0.8% of the spray volume in droplets less than 150 µm compared to 5.1% and 14.1% with the foaming and D8-45 nozzles. As explained above, the droplet spectrum for the D8 nozzle was produced using a different measuring system, at a higher pressure, and for water only. Addition of Delfoam decreases droplet size (cf. D8-45 with water and D8-45 with water plus Delfoam—Fig. 2); reduction of pressure would increase droplet size. The data used for the D8 spectrum must therefore be treated with caution. Although the foaming nozzle produced a smaller proportion of driftable droplets than the D8-45, with droplet sizes below about 100 µm the difference between the two nozzles became less marked.

Deposition

Ground deposits

Mean deposition profiles (Fig. 3) followed the expected pattern for applications made in a strong wind. Peak deposition was displaced downwind of the flight line, and the relative

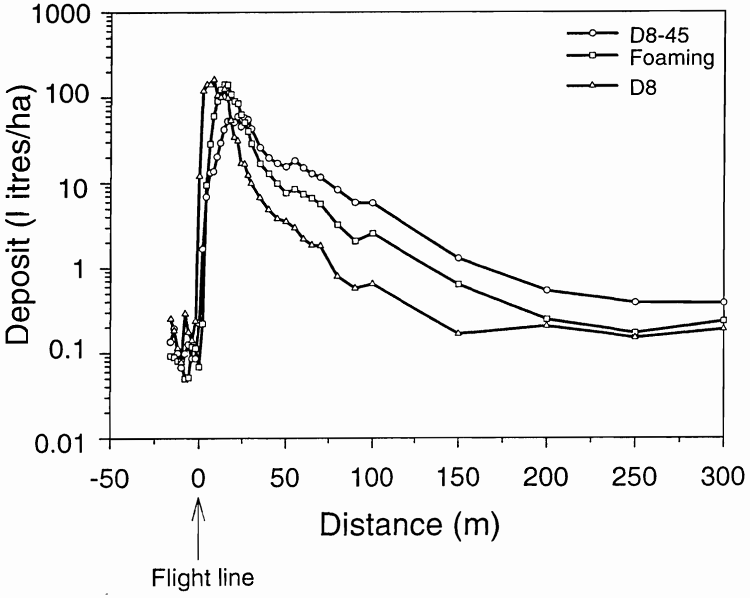

FIG. 3–Mean ground deposition profiles for each nozzle type.

position of the peaks reflected the droplet size distribution of each nozzle type. Maximum deposition was closest to the flight line with the D8 treatment (largest VMD) and was furthest downwind with the D8-45 nozzle (smallest VMD). Downwind from the position of peak deposition, the level of spray deposits dropped off most rapidly with the D8 treatment and least rapidly with the D8-45, and between 50 and 200 m downwind there were statistically significant differences between all treatments (Fig. 4). However, beyond 200 m downwind there was no significant difference in deposition between the D8 and foaming nozzle treatments and at 300 m downwind there was no difference between any of the treatments.

The mean deposition profiles (Fig. 3) showed some evidence of increased deposition at 300 m downwind compared to 250 m downwind with the D8 and foaming nozzle treatments. For the foaming nozzle, this was probably due to contamination of the 300-m sample taken during the second replicate, where there was a large increase in deposition in contrast to the other two replicates. With the D8 treatment, however, there was a consistent increase between 250 and 300 m. It seems unlikely that samples from this location were consistently contaminated and, although the level of deposition at this distance was close to the confident measurement limit of the analytical method, there is no reason to discount this result.

Of the covariates tested, only windspeed was statistically significant ($p < 0.05$) and then only at downwind distances of 50 and 100 m. Increasing windspeed resulted in increased deposition.

Rotorod deposits

The quantity of airborne spray deposited on rotorods (i.e., the airborne spray flux) fell approximately exponentially with distance downwind (Fig. 5). There was evidence of rotorod overloading and centrifugal stripping (i.e., loss of excess deposit through centrifugal

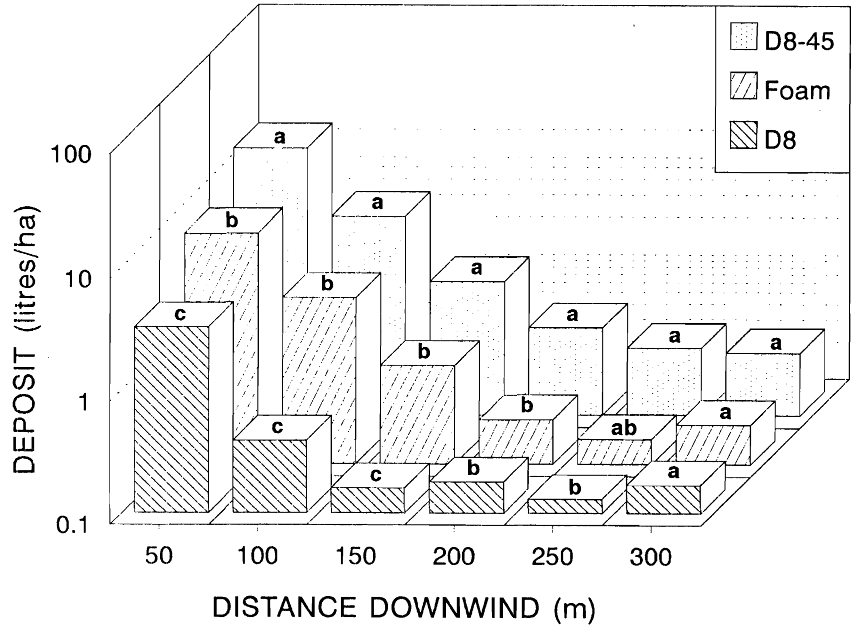

FIG. 4–A comparison of mean ground deposition for selected downwind locations; for each distance, treatments with the same letter are not significantly different at the 5% level according to Fisher's Protected LSD.

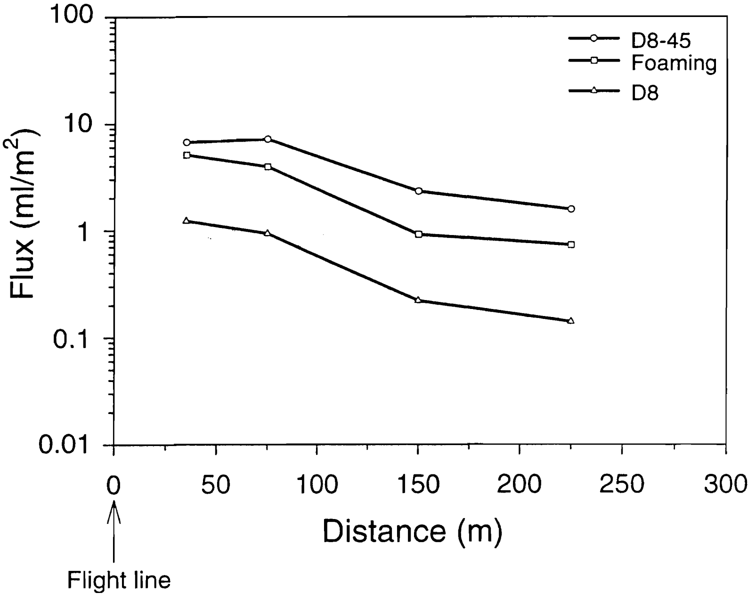

FIG. 5–Airborne spray flux profles for each nozzle type.

force) at the 35-m location. Centrifugal stripping of excess deposit is known to be a problem with rotorods (Houle 1987). This effect was greatest with the D8-45 treatment because it produced the smallest droplets, and least with the D8 treatment. The D8 nozzle reduced airborne flux by almost an order of magnitude compared with the D8-45, with the foaming nozzle being intermediate. All pairwise comparisons showed statistically significant differences between nozzle types in the amount of spray deposition ($p < 0.005$ for all). Out of the covariates tested, spray release height alone was statistically significant for all sampling locations, with increased airborne flux as release height increased.

DISCUSSION

Spray drift from three nozzle types was assessed by measuring deposition on steel plates placed on the ground and on rotorod samplers. Data collected by these two methods showed different results. Deposition on steel plates showed that peak deposition was greatest and closest to the flight line with the D8 nozzle, followed by the foaming and D8-45 nozzles (Fig. 3). As the spray cloud moved downwind, the deposition profiles crossed over as deposition decreased most rapidly with the D8 treatment and then the foaming nozzle. However, beyond distances of about 150–200 m the three deposition profiles began to converge and differences among treatments were not statistically significant at the downwind extremes. Thus, using the deposition data alone it could be concluded that there are no large differences between nozzle types with respect to their long-distance drift potential. However, airborne spray flux data from rotorod samplers (Fig. 5) showed that there were large differences between the nozzles in terms of airborne flux.

These contradictory findings are artefacts of the two methods of sampling spray deposits. As a spray cloud moves downwind, droplets fall not only under the effect of gravity but are also influenced by air movement (wind and turbulence). Large droplets reach the ground rapidly because their sedimentation velocities (settling rates) are usually high compared with surrounding air movements. Droplets within this size range are efficiently collected by steel plates on the ground. However, as droplet size decreases to the "driftable" size range, sedimentation velocities are generally low compared with the speed of surrounding air. The net effect is that droplet size decreases with distance downwind and eventually the very small droplets remaining airborne fall so slowly that their motion is completely dominated by local wind movement, especially under the strong winds experienced during this trial. Thus, horizontal spray sampling surfaces placed on the ground are inefficient collectors of very small droplets and cannot be relied on to measure long-distance drift. However, rotating-rod samplers efficiently collect small airborne droplets and provide a much better index of drift potential.

Results from measurements of airborne spray flux clearly demonstrate that the potential for downwind spray drift can be substantially reduced by using a D8 nozzle pointing straight back. Foaming nozzles significantly reduced airborne flux compared with the D8-45 treatment, but to a much lesser extent than the D8 nozzle.

In this study, levels of downwind deposition were generally higher than those found in other drift trials. Riley *et al.* (1989) concluded that, in general, a 100-fold decrease in deposit can be expected at 100 m downwind. This level was exceeded with the D8 treatment, but the foaming nozzle and D8-45 treatments resulted in deposit reductions closer to 60- and 12-fold, respectively. The higher levels of downwind deposition observed in this experiment can probably be attributed to the unusually strong winds experienced throughout the day and the greater spray release height compared with other trials. Although the high windspeed was not realistic in the operational sense, it proved advantageous in that it was consistent in terms of both direction and strength, and was ideal for comparing the drift potential of the three nozzles. Furthermore, the consistency of meteorological conditions and accuracy of flying throughout the day contributed to an excellent replicated data set for these comparisons.

These findings suggest that a D8 nozzle orientated straight back would be an excellent choice for spraying herbicides in situations where it is important to minimise spray drift. The reduced drift potential is achieved at the expense of a large increase in the volume median diameter (VMD). The practicalities of operational spraying with such large droplets must be considered in terms of both biological efficacy of the herbicide and deposit variation. Problems with biological efficacy may be overcome with the use of suitable additives (e.g., organo-silicone surfactants). However, the sharp cut-off in the swath pattern produced by large droplets may lead to unacceptable levels of striping if flightline separation is not uniform. Since these studies were undertaken, the use of D8 (or D6) nozzles pointing straight back and with no swirl plates has been adopted by at least one major forestry company (Forestry Corporation of New Zealand Ltd). Excellent results have been reported with no problems relating to reduced efficacy or striping (Mark Forward, pers. comm.). Foaming nozzles would be an acceptable alternative to the D8 type in situations where spray drift does not constitute a hazard. They reduce drift when compared with conventional D8-45 nozzles and their effect on VMD is less extreme than that of D8 nozzles.

CONCLUSIONS

Spray deposition downwind of a single flight line can be substantially reduced by use of D8 nozzles pointing straight back in preference to either D8-45 or foaming nozzles pointing straight down.

Foaming nozzles reduced airborne spray flux when compared with conventional D8-45 nozzles, and did not have such an extreme effect on VMD as D8 nozzles. Flux at or beyond 35 m downwind was significantly lower with the D8 treatment.

Spray deposits measured on horizontal sampling surfaces placed on the ground do not provide a good indicator of drift potential.

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