A wedge shaped bluff plate air-assisted sprayer: I. Spray deposits on artificial targets

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Summary

An air-assisted field crop sprayer consisting of a wedge shaped bluff plate placed in front of a spray boom was designed and used to evaluate spray deposition on small horizontal and vertical artificial targets placed at ground level. Smoke generators were used to examine air movement around and behind the bluff plate. The spray boom, fitted with high and low volume flat fan and hollow cone nozzles, and slotted rotary sleeve atomizers, was located behind the bluff plate. Results were compared with those of a conventional spray boom fitted with the same nozzles.

A number of spraying parameters were evaluated by spraying a suspension of a fluorescent pigment onto the targets and measuring the deposits using a fluorescence spectrophotometer. On vertical targets, the bluff plate treatments gave deposits that were on average about four times greater than when nozzles were used without a bluff plate. On horizontal targets, deposits were lower than on vertical targets, with no significant differences between bluff plate and non bluff plate treatments. There were significant effects due to nozzle type. In most treatments, hollow cone nozzles resulted in greater deposits than with the other nozzles, both with and without the bluff plate. However, differences between the various nozzle treatments were smaller than those due to the bluff plate and not consistent between nozzles. As the bluff plate height above the ground was increased, spray deposits on artificial targets decreased. With the gap between the bluff plate and the ground set at zero, nozzle height had no significant effect on the quantity of spray deposited. With spray volume, the amount of pigment deposited increased rapidly up to about 15 L ha^{-1}, then levelled off and decreased slightly to 50 L ha^{-1}. With spraying speed, the amount of pigment deposited increased rapidly between 5 and 10 km h^{-1}, but further increases in spraying speed, up to 45 km h^{-1} produced only a small further increase in the amount of pigment deposited. Mean droplet size (in the range 100–250 µm v.m.d.) had no significant effect on the amount of pigment deposited.

Introduction

Conventional spray booms give poor spray deposition on the undersides of foliage and in the lower canopy, and spray drift, especially with fine droplets, can be excessive (Furness and Combellack 1999). Spray deposition is affected by changing droplet trajectories, such as by aiming nozzles forwards or backwards relative to the direction of travel, or by increasing travel speed, which can increase spray deposition, (Richardson 1987, Richardson and Combellack unpublished, Taylor and Shaw 1983). Spray deposition is also affected by factors such as the nature of the leaf surface, droplet size and velocity, surface tension and viscosity (Hartley and Brunskill 1958, Holly 1964, Lake 1977, Lake and Marchant 1983, Taylor and Shaw 1983). However, droplet size still needs to be relatively large to avoid spray drift, larger drops reduce coverage thereby reducing efficacy at lower spray volumes, and the variability of the deposit may be increased with horizontal droplet trajectories (Combellack 1981, Holly 1964, Richardson 1987).

The advantages of using air assisted spraying, the parameters for efficient air assisted spraying and problems with air deflectors and covered booms were reviewed by Furness (1991), and Furness and Combellack (1999). In particular, air assistance increases spray deposition and penetration into crop canopies and reduces spray drift with fine droplets, thereby enabling the use of lower spray volumes and higher travel speeds, and the ability to work in windy conditions. Systems that produce large volumes of air at low velocity combined with turbulence give the best coverage (Furness 1991, Randall 1971, Furness and Pinczewski 1985).

A simple bluff plate air assisted sprayer using rotary drum atomizers was ideal for improving droplet deposition and reducing spray drift with, high speed (20–30 km h^{-1}), very low volume (10–20 L ha^{-1}) spray application to 0.5 m tall field crops (Furness 1991). Bluff plates are simple, contain no moving parts, and generate air movement by the movement of the spray vehicle itself. However, on soil and weeds less than 4 cm tall, low volume application of herbicides using a simple bluff plate sprayer with rotary drum atomizers gave poorer weed control than a conventional spray boom with hydraulic fan jet nozzles (Fulton and Furness 1988). On weeds 10–15 cm tall the simple bluff plate sprayer at 10 and 20 L ha^{-1} and 20–30 km h^{-1} gave similar weed control to a conventional spray boom at 40 and 80 L ha^{-1} and 10 km h^{-1} (Fulton and Furness 1988).

A possible reason for the poor performance of the simple bluff plate sprayer on short targets was the large quantity of air passing underneath the bluff plate, which reduced the ability of the spray cloud to reach sites close to the ground. In an attempt to overcome this problem, a wedge shaped bluff plate was constructed to increase frictional forces against airflow, thereby reducing the amount of air passing underneath the bluff plate.

Controlled droplet atomizers (CDA), especially spinning disc atomizers, have been promoted as a means to reduce run off and to improve spray deposition, uniformity and efficacy (Bals and Ayr 1978, Matthews 1979). However, with their use on large, high speed, mechanized spray booms without air assistance, as used in dryland cereal spraying, it has not been possible to significantly reduce chemical rates or spray volumes compared with standard fine flat fan nozzles (Pierce 1985). Problems have included: spray drift and striping in windy conditions and at high travel speeds, maximum flow rates that are too low for high speed operation, and poor reliability of drive systems and bearings, especially in dusty conditions. However, rotary atomizers suspend droplets in larger volumes of air than conventional hydraulic nozzles. Hence they could have advantages for air assisted spraying.

This paper reports work which compares spray deposition on artificial targets achieved by a wedge shaped bluff plate (BP) sprayer, fitted with both flat fan and hollow cone hydraulic nozzles, and slotted rotary sleeve atomizers (SRSA) (Furness *et al.* 1993), and a conventional spray boom fitted with the same nozzles. Observations on air movement patterns behind and around the bluff plate using smoke generators are also reported. As well as the main bluff plate effects, the effect of nozzle type, atomizer rotational speed (droplet size), target orientation, bluff plate height, nozzle height, spray volume and ground speed on spray deposition with the bluff plate sprayer are also reported.

Materials and methods

Spray equipment (Figure 1)

A trailed bluff plate spray boom was constructed (1989) and towed by a four wheel drive cab-chassis vehicle. Major components included a 6 m long wedge shaped bluff plate with two stiff rubber skirts front and back for clearance. A 6 m boom supporting four 100 mm diameter SRSA, driven initially by small direct current (d.c.) and later by high frequency, 3-phase a.c. electric motors (Furness *et al.* 1993), and 12 triplet hydraulic nozzle assemblies (Hardi Spraying Equipment South Australia Pty Ltd.), was mounted behind the bluff plate. The location of the nozzles relative to the bluff plate could be adjusted vertically and horizontally, and the bluff plate could be removed for conventional boom treatments on the first experimental sprayer. The configuration of the components are given in Figures 1a,b.

The SRSA were normally run at 7000–7500 rev min^{-1} which produced a droplet size (Walton and Prewett 1949, Furness *et al.* 1993) of about 100–150 µm v.m.d. Lower rotational speeds were used in one experiment to determine the effect of rotational speed (droplet size) on the amount of pigment deposited. Liquid feed to each atomizer was via by three 12 m long microtubes, 1.5, 3.0 and 4.0 mm internal diameter. Flow rate was controlled by a combination of microtube diameter and pressure. Spray volumes in the range 5–50 L ha^{-1} were applied at speeds ranging from 5–45 km h^{-1}. There was a set of on/off taps for each diameter of tubing. An option of all three microtubes operating could also be used for maximum flow rate.

The following hydraulic atomizers (plumbed with standard 12 mm hose) were fitted to the triplet assemblies: Spraying Systems TX 6 or Delevan HC 6 hollow cone nozzles, Albuz Orange, No. 2 flat fan nozzles and Hardi 4110-12 flat fan nozzles. Spray volumes of 20, 30, and 60 L ha^{-1} were applied at speeds of 15 and 30 km h^{-1}.

Compressed air was used to feed liquid to the nozzles. Two air pressure regulators were used to adjust pressure in two 45 L and one 20 L stainless steel pressure vessels containing the spray liquid. A small stationary motor provided the necessary power. The liquid distribution system was mounted on the tray of the spray vehicle (Figure 1c).

A second conventional (no air assistance) 6 m Hardi linkage boom with triplet

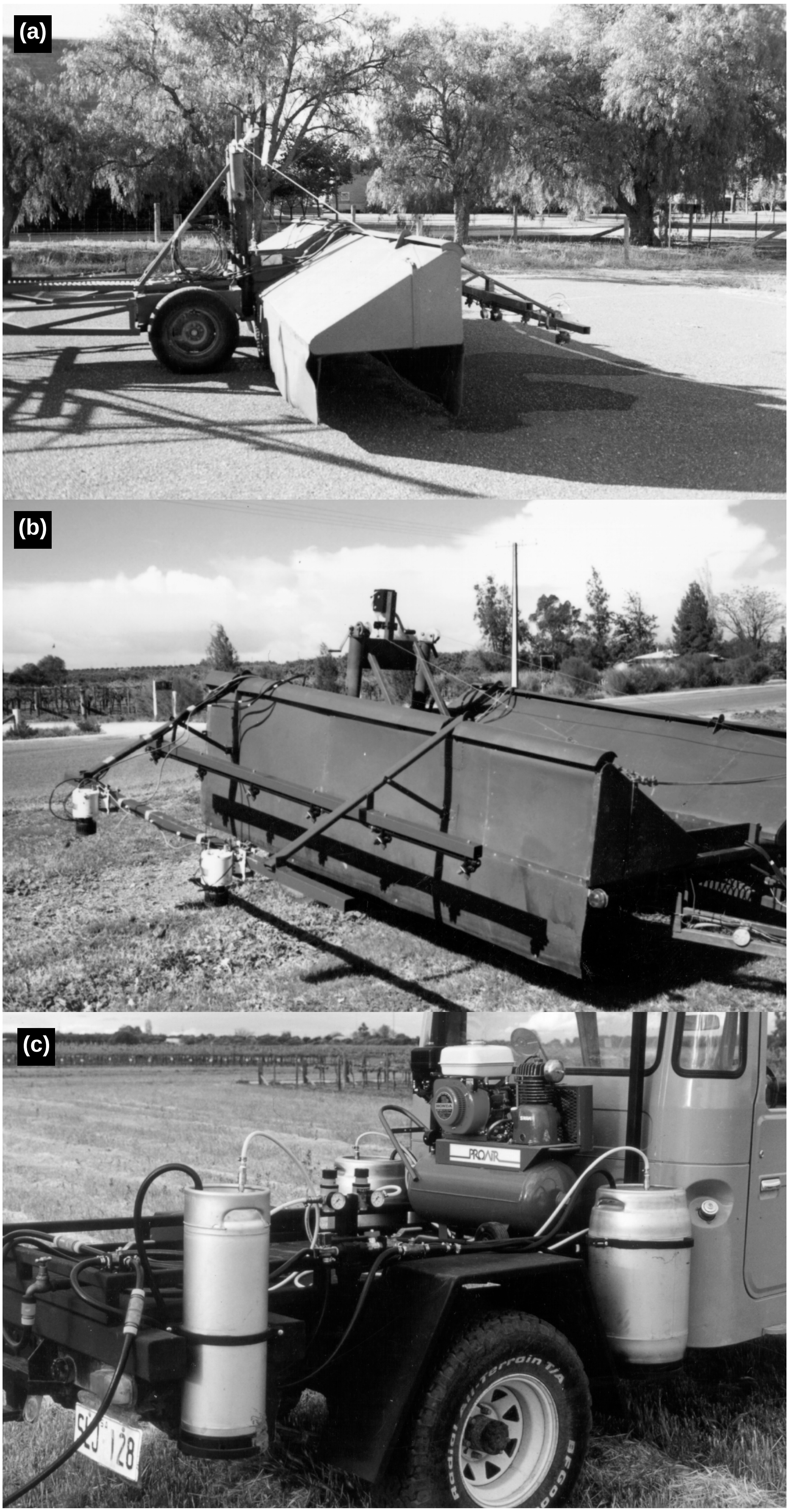

Figure 1. Bluff plate experimental sprayers (a) Side view of second sprayer showing bluff plate and booms, (b) View of sprayer in folded position with booms containing nozzles in spraying position showing both the hydraulic nozzles and triplet assemblies, and the slotted rotary sleeve atomizers and a.c. electric drive motors, (c) Side view of spray vehicle showing liquid distribution system based on compressed air.

assemblies and the same hydraulic nozzles as above was fitted to the back of the spray vehicle for the non-bluff plate treatments. The bluff plate boom trailer was unhitched when using the conventional boom.

Air movement patterns behind the bluff plate

Smoke trails from a smoke generator located in a variety of positions in front of and behind the bluff plate were observed. In addition, observations were made using a piece of wool attached to a pole and observing the direction of wool to determine the direction of air currents. Observations were made by an observer seated on top of the bluff plate, and by observers on the ground and in a second vehicle travelling alongside the spray rig.

Cardboard models (to scale with the experimental sprayer) of a wedge shaped bluff plate were also made to observe smoke trails around the bluff plate model in the laboratory. The model was placed on a table and air from a centrifugal blower from an evaporative cooler was blown parallel to the table at the model.

These observations provided a guide to the air movement patterns created by the bluff plate (Figure 2), which were similar both in the field and around the laboratory models.

Fluorescent pigment solution

A suspension concentrate formulation of yellow fluorescent pigment containing 400 g L^{-1} pigment (South Australian Research and Development Institute (SARDI), Loxton Centre) was used to assess spray coverage. The optimal excitation and emission wavelengths were 468 nm and 502 nm respectively (measured by scanning on a Perkin Elmer 650-10S fluorescence spectrophotometer).

Artificial targets

Artificial targets were rectangular pieces of matt black cardboard, 1 × 4 cm. Vertical targets (long side vertical, and with the flat surface facing towards the direction of travel of the sprayer) were located by a small clothes peg stapled to the soil surface with a wire loop pushed into the soil. Horizontal targets were held parallel to and about 0.5 cm above the soil surface using the same pegging system. Targets were flexible enough to return to their correct position if hit by the sprayer skirts.

For each run, horizontal and vertical targets were arranged in a line perpendicular to the direction of travel with one target every 33 cm for nine locations either side of centre then another two locations at 1 m intervals to examine deposition outside the swath of the spray boom. One to three runs were made per treatment per day and repeated from one to five times on different days, with one to three

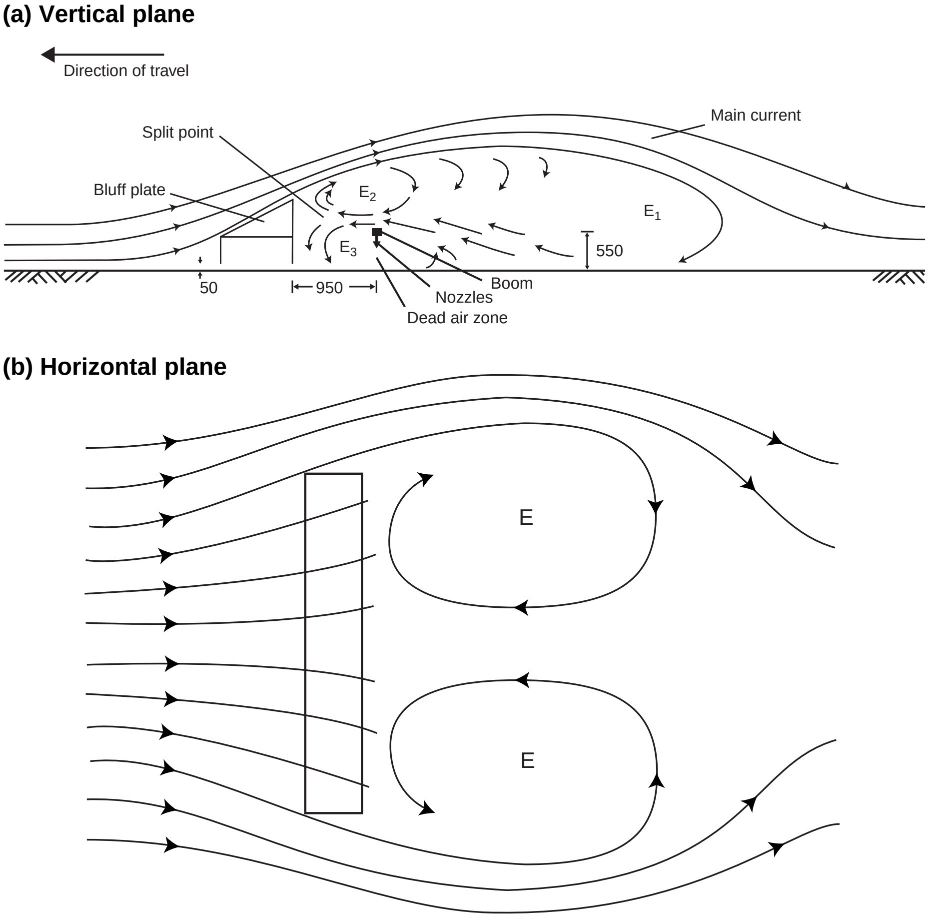

Figure 2. Air movement patterns relative to a bluff plate, determined from observations of smoke movements in smoke generator studies (a) Vertical plane, (b) Horizontal plane. (←) direction of bluff plate travel; (E1, E2, and E3, vertical plane and E, horizontal plane) principal eddies in the static circulatory zone of stalled air leeward of the bluff plate. Height of bluff plate: 1 m; total length of static zone: 5 m approx; other measurements on figure in mm. Drawings to scale.

replicates (runs) each day. For quantitative comparisons between treatments, only data within 3 m either side of centre, within the swath of the boom, were used. All artificial target work was carried out on a vacant block of land at the SARDI Loxton Centre. The direction of travel was east to west. Wind speed was measured using a pith ball wind meter. All other weather parameters were available from the weather station on site about 50 m from the trial site.

The amount of pigment deposited per cm^2 was assessed by surface scanning the deposit on a Perkin Elmer 650-10 S fluorescence spectrophotometer using the method described by Furness and Newton (1988).

Effect of the bluff plate and nozzle type on the amount of spray deposited on small vertical targets at ground level

The seven treatments shown in Table 1, some with and some without the bluff plate, were used to apply the fluorescent pigment at a rate of 80 g ha^{-1} (treatments 1 to 5) and 120 g ha^{-1} (treatments 6 and 7) to vertical artificial targets. The 120 g ha^{-1} rate was used to increase precision on the fluorescence spectrophotometer for treatments giving a low reading and a correction was made for the increased amount of pigment deposited. Changes in concentration of the pigment had little effect on atomization and deposition (Furness and Newton 1988). Nozzle pressure was 400 kPa, with a small adjustment to achieve the desired flow rate.

Table 1. Treatments used to apply fluorescent pigment to vertical artificial targets.

Treatment	Spray volume ($L\ ha^{-1}$)	Speed ($km\ h^{-1}$)
1. Cone + BP	20	30
2. Fan + BP	30	30
3. SRSA + BP	20	30
4. Cone	20	30
5. Fan	60	15
6. Fan	30	30
7. SRSA	20	30

Abbreviations: Cone = (SS TX 6) hollow cone nozzle, Fan = (Albuz orange, No 2) flat fan nozzle, SRSA = slotted rotary sleeve atomizer, BP = bluff plate.

Application of the treatments required a full day and 3–7 days were required between each of five treatment days for fluorimetric assessments. Most, but not all treatments, were applied on each treatment day, and there were three replicates per treatment each day (15 replicates in total). Background readings each day were taken from 21 unsprayed targets as controls and the mean reading subtracted from the treatment readings to give the reading for pigment deposit. The trials were conducted during March 1989. Conditions were fine and sunny and the mean maximum temperature ranged from 23 to 29°C. Maximum wind speed was low, around 5–10 km h^{-1} on all days, but the direction varied. The data was arranged (mirror image where required) so that the wind direction (or a component) was always from the left side. Wind had little effect on deposition with the bluff plate treatments because air movements created by the bluff plate were of greater magnitude. However, it would have increased deposition slightly in non bluff plate treatments.

Another experiment was conducted on 25 April 1989 to compare deposits on horizontal and vertical targets. The number of replicates was reduced to three, all on one day, and the number of swath positions to nine at 1 m intervals giving a total of 189 readings plus 14 background unsprayed control readings. Conditions were fine and sunny with a temperature of 26°C (dry bulb) and 18°C (wet bulb), and a wind speed of 5–10 km h^{-1} from the north-east.

Effect of bluff plate height on spray deposit

To determine the effect of bluff plate height on spray deposits, the bluff plate height was adjusted so that the skirts were 0, 100 and 200 mm above the ground. Cone nozzles, 500 mm above the ground were used to apply 120 or 80 g ha^{-1} of pigment at a spray volume of 20 L ha^{-1} and a speed of 30 km h^{-1}. Ten swath positions at 1 m intervals and three replicates were used for the three treatments. Twelve readings were taken from unsprayed targets as background controls. The tests were carried out on 13 June 1989. Conditions were fine and overcast, with a temperature of 10°C (dry bulb), and wind speed of 0-4 km h^{-1} from the north-west.

Effect of nozzle height (with the bluff plate) on spray deposit

To determine the effect of nozzle height on spray deposits an experiment was conducted on 31 August 1989 using nozzle heights of 250 and 500 mm above the ground. Fluorescent pigment was applied at 80 g ha^{-1} using a spray volume of 20 L ha^{-1} at a speed of 30 km h^{-1}, using the hollow cone nozzles. The gap used between the bluff plate skirts and the ground was 0 mm. The number of swath positions was reduced to four, at 1 m intervals, and there were six replicates giving a total of 48 observations for the two treatments. Four readings were taken from unsprayed targets as background controls. Conditions were fine and sunny with a temperature of 18°C (dry bulb) and 15°C (wet bulb), and wind speed was gusting to 20 km h^{-1} from the west / south-west.

Effect of spray volume on spray deposit

An experiment was conducted on 28 February 1998 to determine the effect of spray volume on spray deposits. The bluff plate was operated at 0 mm above the ground using the SRSA. The SRSA's at 7000 rev min^{-1} and at 500 mm above the ground were used to study this and the next two parameters because of the ease of adjusting spray volume and the wide range of flow rates available with the one atomizer. Concentration was adjusted to apply 80 g ha^{-1} of pigment at a speed of 30 km h^{-1}. Eighteen swath positions and three replicates were used for each of seven treatments. Twenty seven readings were taken from unsprayed targets as background controls. Conditions were fine with light cloud, a temperature of 34°C (dry bulb) and 19°C (wet bulb) and with a wind speed 0-5 km h^{-1} from the north-east.

Effect of ground speed on spray deposits

To determine the effect of ground speed on spray deposits, the bluff plate was operated at 0 mm above the ground using the SRSA. Flow rate was adjusted to apply 80 g ha^{-1} of pigment in a volume of 10 L ha^{-1}. Eighteen swath positions and three replicates were used on each of two days. Twenty unsprayed targets each day were used as background controls. On 16 February 1989, the speeds used were 10, 20, 30 40 and 45 km h^{-1}. Conditions were fine with a temperature of 18.5°C (dry bulb) and 16.5°C (wet bulb). Wind speed averaged about 5 km h^{-1} from the south. On 23 February 1989, the speeds used were 5, 10, 20, 30 and 35 km h^{-1}. Conditions were fine with a temperature of 30°C (dry bulb) and 16°C (wet bulb), and a wind speed of 0–5 km h^{-1} from the south-east.

Effect of droplet size on spray deposits

To determine the effect of mean droplet size on pigment deposit, the bluff plate was operated with zero ground clearance at 30 km h^{-1} using the SRSA at 500 mm height to apply 80 g ha^{-1} pigment in 10 L ha^{-1} spray volume on 10 February 1989. Droplet size was varied from a mean size of about 100 µm v.m.d. to a mean size of about 200–250 µm v.m.d. by using rotational speeds of 7100, 6480, 5500, 4450 and 3540 rev min^{-1} (Furness *et al.* 1993, Walton and Prewett 1949). Twenty swath positions and three replicates were used for each treatment. Seventeen unsprayed targets were used as background controls. Conditions were cloudy but fine, with a temperature of 20°C (dry bulb) and 14°C (wet bulb) with a wind speed gusting up to 10 km h^{-1} from the west.

Results and discussion

Observations on air movement patterns associated with the bluff plate

Observed air movement patterns relative to the bluff plate are shown in Figures 2a,b. Effects in the vertical plane are shown in Figure 2a. Air flowing over the top of the bluff plate descended to the ground about 5 m behind the bluff plate. In the relatively static air zone behind the bluff plate, air moved towards the top of the bluff plate to a split point just below and behind the top of the plate, creating two main circulatory zones above and below the split point as shown. Similar effects (Figure 2b) were observed in the horizontal plane due to sideways displacement of air around the bluff plate. With wider bluff plates, as used in commercial sprayers, we suggest that these sideways movements would become less significant, because the vertical height of the bluff plate becomes smaller relative to the width.

Effect of the bluff plate and nozzle type on the amount of pigment deposited on vertical targets at ground level

The effects of the bluff plate and nozzle type on the average pigment deposit (expressed as log (ln) mean), on vertical targets, together with LSD values are shown in Table 2. Deposits (not transformed) across and outside the swath are plotted

Table 2. Effect of the bluff plate and nozzle type on fluorescent pigment deposit on vertical artificial targets.

Treatment	Log (ln) mean deposit (µgm cm^{-2})
1. Cone+BP	0.028
2. Fan+BP	-0.335
3. SRSA+BP	-0.402
4. Cone 20	-1.085
5. Fan 60 15	-1.590
7. SRSA 20	-1.816
6. Fan 30	-1.907

Values are the least squares mean log dye reading for the seven treatments from the combined analysis of variance: Because these means are based on different numbers of observations, there is no single LSD. There are in fact three LSDs (P=0.05) corresponding to pairwise comparisons between:

Treatments	LSD
1,2,3,5 and 6	0.699
(1,2,3,5,6) vs. (4 or 7)	0.882
4 vs. 7	0.989

in Figure 3 to show the variability across the swath. Analyses at each swath position in Figure 3 were not attempted because of the high variability and small number of samples at each position.

A combined analysis over all days was carried out to examine the main treatment effects. The combined analysis was like a split-plot in which the main-plot error was the day × treatment interaction. Because the data were incomplete (not all treatments on all days), ordinary analysis of variance could not be used. Instead, residual maximum likelihood was used to estimate the variance components and then generalized least squares to estimate treatment means. (Note that these least squares means are different from ordinary means because they 'adjust' for the incompleteness). The least squares mean log (ln) pigment deposits for the seven treatments from the combined analysis and their significance are given in Table 2. Log (ln) transformations were required to produce normality for analysis. The data to be compared were mean deposits over all swath positions. That is, the analysis of variance treated all swath positions as one mean. Only data to 2.667 m either side of centre was analysed because the other sites were outside the swath of the spray boom. The data was also analysed for each day (Table 3). Day 1 was omitted from the analysis because a number of tags were run over and damaged by the sprayer. The means produced a data set of 72 observations. A completely randomized analysis of variance (CRAOV) of the log transformed data for each day revealed highly significant differences between treatments (P=0.0001) on all days. In addition to the main effects, there is also some interaction between treatment and day, since there are some changes in the treatment rankings from one day to the next. Hence it is likely that weather conditions influenced the deposit patterns. However, these differences were small.

The bluff plate resulted in a large (2–4 times) increase in the amount of pigment deposited with all nozzles. (Plots (Figure 3) also suggested the following trends, but these were not analysed (reasons above)). With the bluff plate, the greatest deposits occurred near the extremities of the swath. Low deposits at + or – 0.667 m in some bluff plate treatments was due to targets being run over by the wheels of the spray vehicle in some of the runs. Hence these swath positions should be ignored when comparing treatments. Without the bluff plate, deposits were greatest near the centre of the swath, probably due to air movement around the spray vehicle having an effect on deposits similar to the bluff plate. If air movement was causing an increase in deposits behind the vehicle, this would not occur with wider, towed behind, commercial booms. A larger trial is required to determine whether these effects are significant.

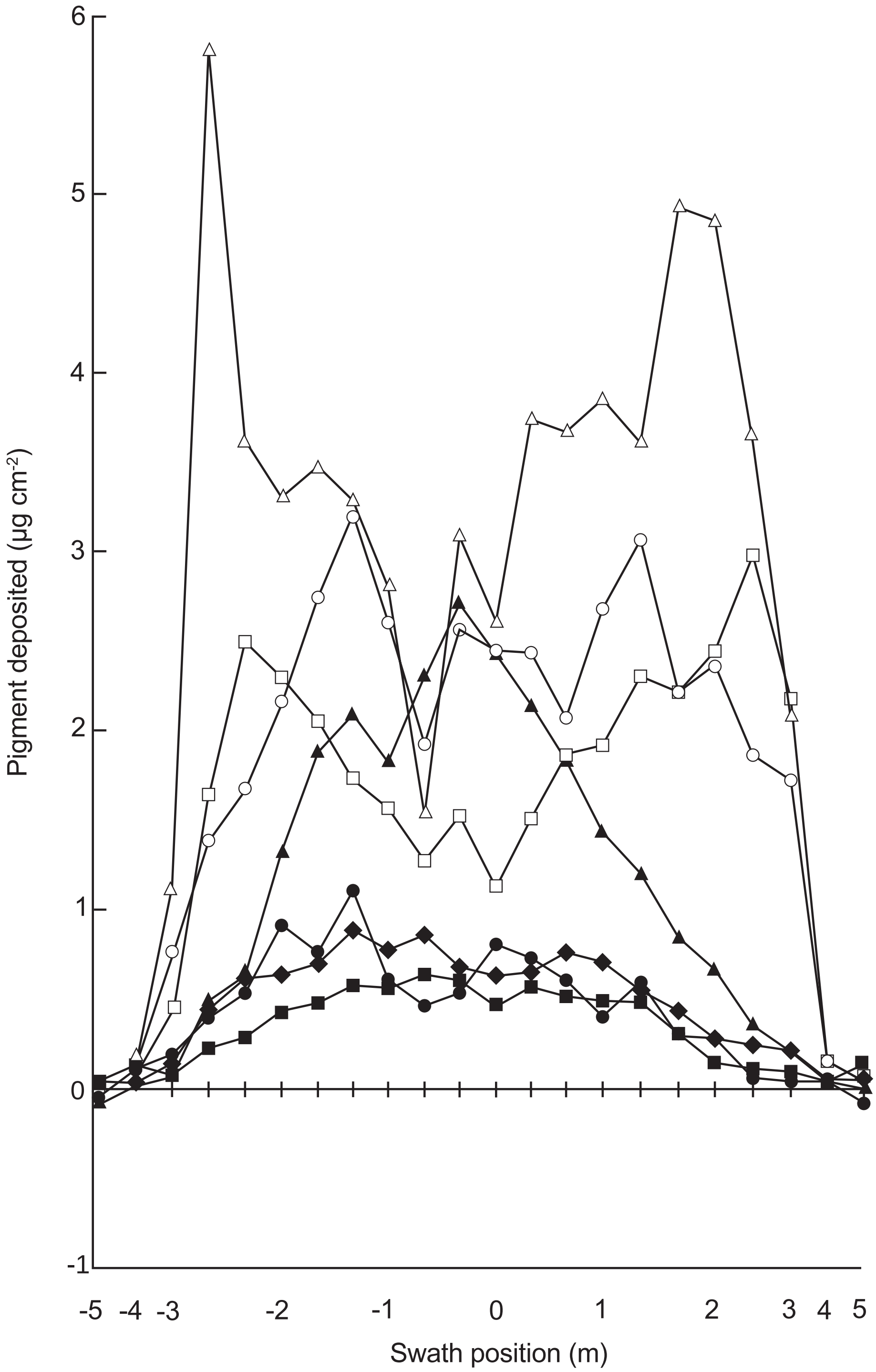

Figure 3. Effect of bluff plate and nozzle type on the amount of pigment deposited on vertical targets. Fan 60 15 (◆): flat fan nozzles, 60 L ha^{-1}, 15 km h^{-1}; Fan 30 30 (■): 30 L ha^{-1}, 30 km h^{-1}; Cone 20 (▲): hollow cone nozzles, 20 L ha^{-1}, 30 km h^{-1}; SRSA 20 (●): slotted rotary sleeve atomizer, 20 L ha^{-1}, 30 km h^{-1}; Fan + BP (□): flat fan nozzles + bluff plate, 20 L ha^{-1}, 30 km h^{-1}; Cone + BP (△): hollow cone nozzles + bluff plate, 20 L ha^{-1}, 30 km h^{-1}; SRSA + BP (○): slotted rotary sleeve atomizers + bluff plate, 20 L ha^{-1}, 30 km h^{-1}.

Poor deposits found on the ground and short targets with the use of a simple bluff plate sprayer (Fulton and Furness 1988), did not occur here with a wedge-shaped bluff plate sprayer, presumably due to reduced airflow underneath the bluff plate.

Nozzle type also had an effect on the amount of pigment deposited, both with and without the bluff plate. The cone nozzles generally gave the greatest pigment deposit, both with and without the bluff plate. However, nozzle effects were smaller and not consistent as with the bluff plate.

Hence cone nozzles were used to study the effects of the other parameters if changes to flow rate or droplet size were not required. Cone nozzles are also being used on the commercial bluff plate boom sprayers now being manufactured. The reasons for improved deposits with cone compared to flat fan nozzles warrants investigation. Reasons could include: at high travel speeds, reduced air vortices as air moves around the more streamlined, curved spray jet produced by a cone nozzle compared to a flat fan jet, the broader band of spray produced (forward and backward as well as sideways droplet trajectories) and greater droplet size uniformity.

Table 3. Effect of the bluff plate and nozzle type on the amount of fluorescent pigment deposited on vertical artificial targets on different days.

Treatment	Log (ln) mean deposit (μg cm^{-2}) Day			
	2	3	4	5
Cone+BP	1.226 a	-0.767 a	-0.517 b	0.171 a
SRSA+BP	0.879 b	-0.998 b	-1.052 c	-0.436 b
Fan+BP	0.224 c	-0.757 a	-0.055 a	-0.752 c
Cone 20	-0.138 d	–	–	-1.146 e
Fan 60 15	-1.045 e	-2.734 c	-1.674 d	-0.907 cd
SRSA 20	-1.557 f	–	–	-1.191 e
Fan 30	-1.686 f	-2.985 d	-1.861 d	-1.095 de
LSD (P=0.05)	0.141	0.214	0.203	0.207

The LSD values are for pairwise comparisons of the log (ln) means. Fluorimetry readings were converted by the correction factor 2.4 to convert to mean pigment deposit in μg cm^{-2}, and for plotting in Figure 3 (Furness and Newton 1988).

Vertical compared to horizontal targets

The effect of the bluff plate and nozzle type on the amount of pigment deposited on horizontal vs vertical targets are shown in Figures 4a,b and Table 4.

With this data, the trends and analyses were similar to that for Tables 2 and 3. Hence details of the analyses are not presented.

On vertical targets, bluff plate treatments deposits were about four times greater than with non bluff plate treatments. On horizontal targets, quantities of pigment deposited were of similar magnitude with both bluff plate and non-bluff plate treatments with no significant differences between any of the treatments. With bluff plate treatments, quantities of pigment deposited were about four times more on vertical than on horizontal targets. With non-bluff plate treatments, deposits were of similar magnitude on both horizontal and vertical targets.

Effect of bluff plate height

As the height of the bluff plate was increased from 0–200 mm the amount of pigment deposited and the variance of the deposit, decreased significantly, especially from 100 to 200 mm, on vertical but not on horizontal targets (Tables 4 and 5). This is thought to be due to an increase in the amount of air flowing underneath the bluff plate as the gap to the ground increases. Hence for maximum deposits with a bluff plate sprayer it is important to keep the gap between the bluff plate and the top of the target close to zero. The increased variance with the bluff plate close to the ground was probably due to sideways air movement, which decreased relative to the nozzles as the bluff plate height above the ground was increased, since the nozzles were kept at the same distance above the ground. We suggest that the effect would be reduced with wider bluff plates (see above).

On the vertical targets, non normal distributions, combined with differing variances, even with log transformations, meant that completely randomized analysis of variance could not be used. Instead, two-sample t-tests were used because they can be based on equal or unequal variances as appropriate. The variance of the 200 mm gap treatment was significantly less than the other two treatments.

On the horizontal targets, log transformations were used to normalize the data, enabling the use of a standard, completely randomized, analysis of variance.

Effect of nozzle height

There was no significant difference in pigment deposits (using a two sample t-test) between nozzle heights of 250 and 500 mm above the targets, using the bluff plate with the skirts set at 0 mm above the ground (Table 6). This suggests that nozzle height is not critical with a bluff plate sprayer as with a conventional, non-air-assisted spray boom.

Effect of spray volume

A plot of pigment deposit vs. spray volume (Figure 5) gave a relationship in which the deposit increased rapidly with spray volume up to about 15 L ha^{-1}, then levelled off and decreased slightly up to a spray volume of 50 L ha^{-1}, with the maximum deposit probably in a spray volume range of 20–40 L ha^{-1}. Commercial bluff plate sprayers are generally being operated in the 20–30 L ha^{-1} range. We suggest that droplet evaporation is a significant factor below 15 L ha^{-1} and run off and droplet bounce starts to occur above about 40 L ha^{-1}. Further investigations to determine the reason for the relationship is warranted.

A 'two-phase linear model' consisting of two intersecting straight lines was appropriate to describe the relationship for analysis. A log transformation of the amount of pigment deposited was used to normalize the data for analysis. The equations that describe the two lines are:

Line 1: $y = -2.1535 + 0.1338 * x$
Line 2: $y = 0.1117 - 0.0027 * x$

(Parameter y = pigment deposit, parameter x = spray volume).

The lines intersect at x = 16.6 and y = 0.066. The true value of intersection may lie anywhere in the range 14 to 19, which is the 95% confidence interval. The adjusted R^2 value was 91%. The slight negative slope of the second line, also means that the point of intersection is also the point of maximum deposition in this model.

Effect of spraying speed

A plot of pigment deposit vs spraying speed (Figure 6) gave a relationship in which the amount of pigment deposited increased greatly as the speed increased from 5–10 km h^{-1}, then increased at a lesser rate with speed from 10–45 km h^{-1}. It seems likely that the effect of the bluff plate is minimal at low speeds but increases rapidly to 10 km h^{-1}, after which further increases in speed produce a substantial but smaller increase in the amount of pigment deposited. Commercial bluff plate sprayers are normally being operated at a speed of 20–30 km h^{-1}. Above 30 km h^{-1}, practical problems tend to limit further increases in travel speed, although where terrain permits, some units will travel faster than 30 km h^{-1}.

Again, a 'two-phase linear model' consisting of two intersecting straight lines was appropriate to describe the relationship. A log transformation of pigment reading was used to normalize the data for analysis. The equations that describe the two lines are:

Line 1: $y = -2.9120 + 0.2488 * x$
Line 2: $y = -0.5613 + 0.0137 * x$

(Parameter y = pigment deposit, parameter x = spraying speed).

The lines intersect at x = 10.0 and y = -0.42. The estimated point of intersection is at a ground speed of 10.0 km h^{-1}. The adjusted R^2 value was 90%.

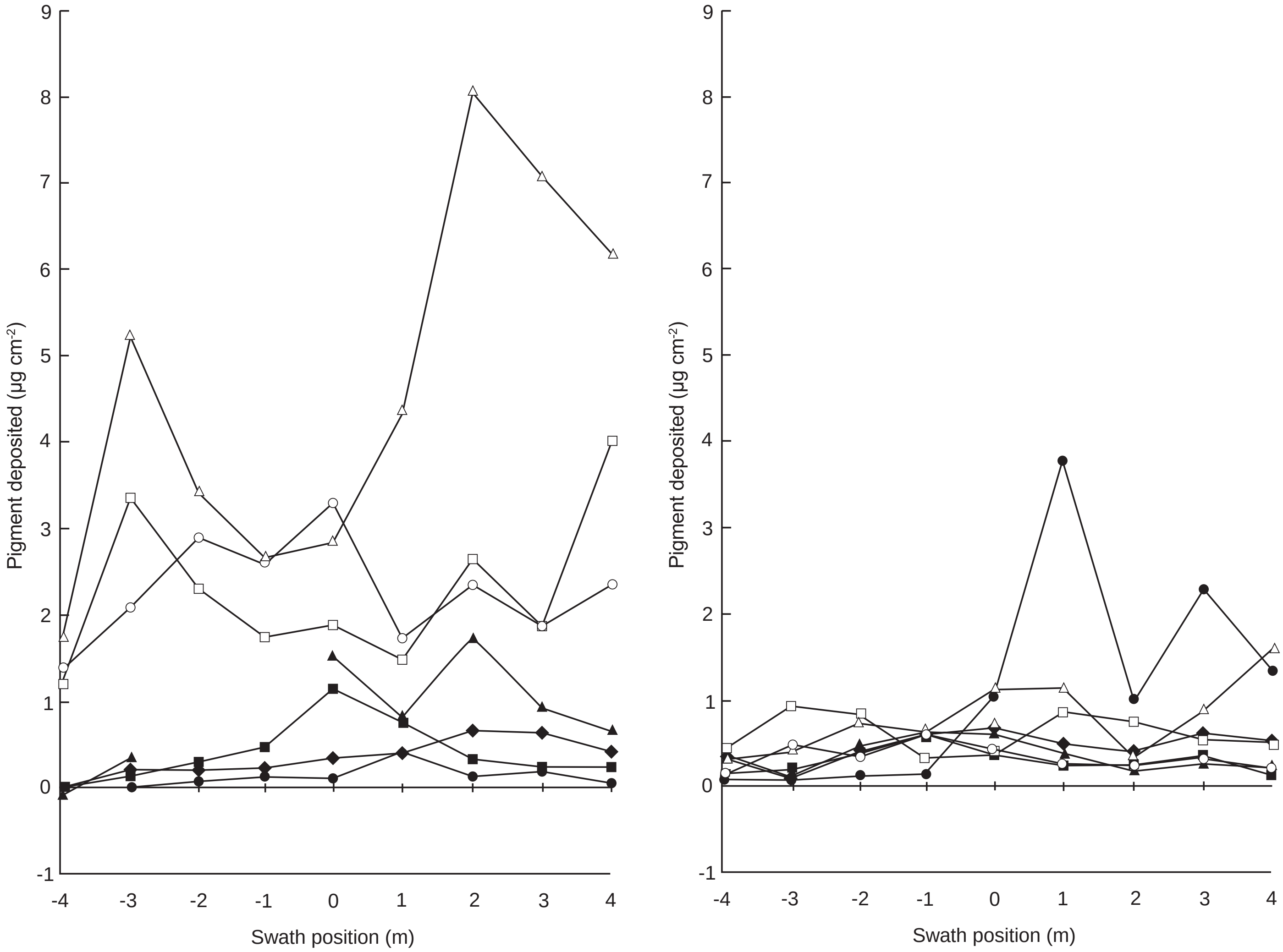

Figure 4. Effect of target orientation on the amount of pigment deposited with a bluff plate sprayer and a conventional boom sprayer (a) vertical targets, (b) horizontal targets. Treatment notation as for Figure 3.

Effect of mean droplet size (atomizer rotational speed)

Analysis of variance (P=0.05) revealed no significant differences in pigment deposit between the treatments (Table 7). Hence in the range tested, SRSA rotational speed had no detectable effect on the quantity of spray deposited by a bluff plate sprayer on vertical artificial targets. According to the work of Walton and Prewett (1949), the expected droplet size range would have been 100–250 µm v.m.d. Observations of impacted droplets indicated that this range was likely to be correct. However, no actual measurements were made.

Table 4. Mean fluorescent pigment deposits and mean log (ln) fluorescent pigment readings on vertical artificial targets sprayed with a bluff plate sprayer, with the bluff plate set at different heights above the ground.

Bluff plate height, mm	0	100	200
Mean deposit, µg cm^{-2}	2.5	2.2	1.5
Mean log (ln) reading	0.0137	-0.1175	-0.4972

The P-values for the two-sample t-tests of the log data were as follows:

Comparison	Variances[A]	Means[B]
0 vs. 200	0.0454*	0.0353*
100 vs. 200	0.0403*	0.0726
0 vs. 100	0.4565	0.4444

[A] P-value for t-test of equal variances.
[B] P-value for test of equal means (test basedon common variance if [A] was not significant; on separate variances if [A] was significant).
* Significant difference (P<0.05).

Conclusions

Air assisted spraying with a wedge shaped bluff plate in front of the spray nozzles resulted in a substantial increase in spray deposits on artificial targets, especially on vertical surfaces, when compared to a standard spray boom without air assistance. The increase in spray deposits occurred on short targets, whereas with a simple bluff plate in earlier work, the increase could only be achieved on tall targets. In addition, the increase was achieved at lower spray volumes and higher spraying speeds than with a conventional non air-assisted boom. These results have been confirmed in subsequent studies on a range of conventional and air assisted broad acre boom sprayers, by Agriculture Victoria (Young 1996). However, in that work, only flat fan nozzles were used on the bluff plate sprayer for comparisons with other booms. Our work indicated that their results with the bluff plate sprayer could have been improved by the inclusion of a treatment with the bluff plate with hollow cone nozzles. The

Table 5. Mean fluorescent pigment deposits and mean log (ln) fluorescent pigment readings on horizontal artificial targets sprayed with a bluff plate sprayer, with the bluff plate set at different heights above the ground.

Bluff plate height (mm)	0	100	200
Mean deposit (µg cm^{-2})	0.73	0.22	0.23
Mean log (ln) reading	-1.356	-2.734	-2.436

The CRAOV of the log (ln) data revealed that there were no significant differences between the treatments (P=0.05). However, the relatively large differences suggest that larger sample sizes may have yielded significant differences, but with the small deposits compared to vertical targets and the arguments in the body of the text, the extra work could not be justified for this study.

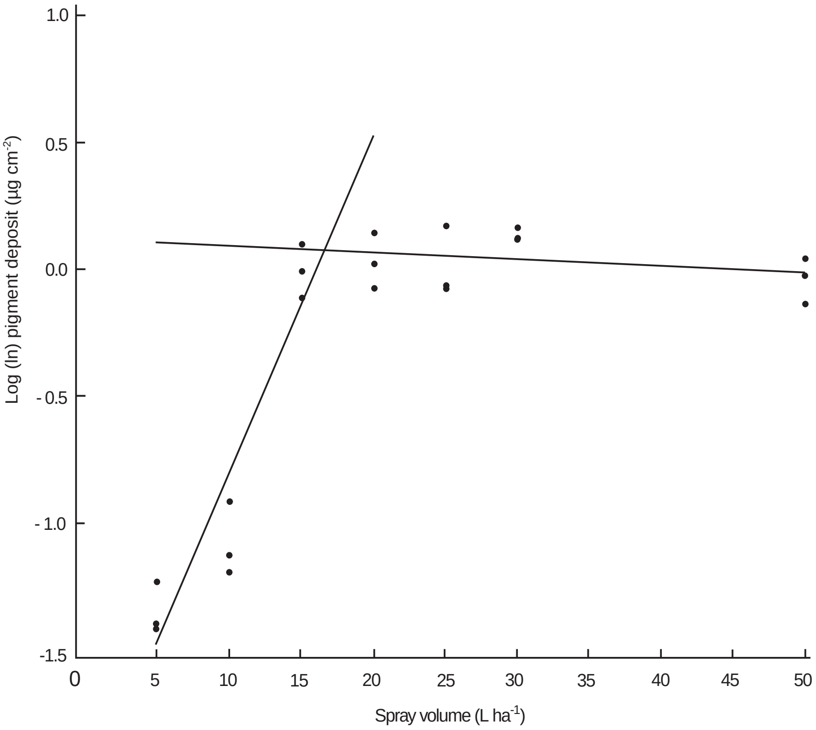

Figure 5. Effect of spray volume on the amount of pigment deposited on vertical targets using a bluff plate sprayer.

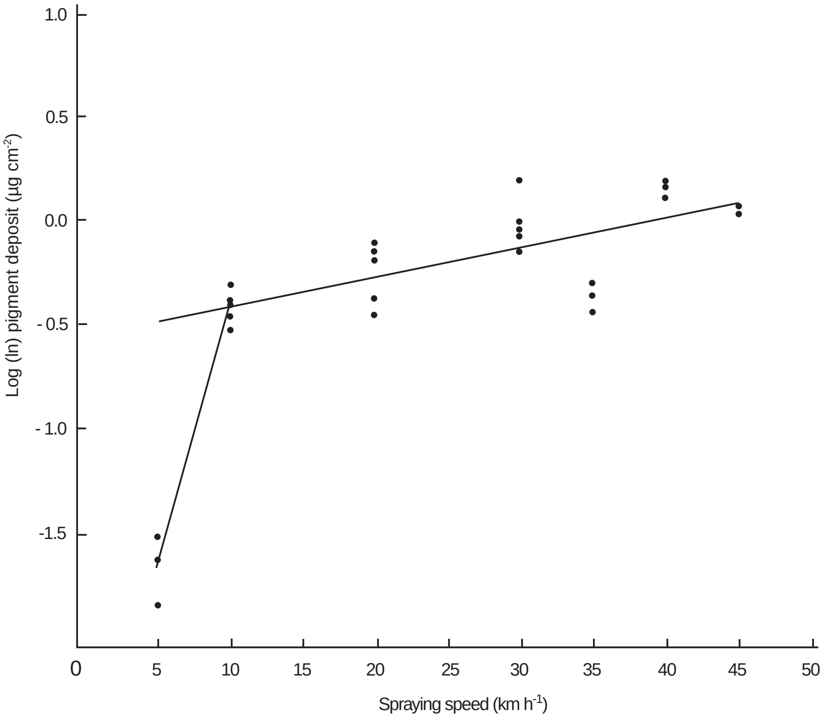

Figure 6. Effect of spraying speed on the amount of pigment deposited on vertical targets using a bluff plate sprayer.

Table 6. Mean fluorescent pigment deposits on vertical targets sprayed with a bluff plate sprayer using two different nozzle heights above the ground, with the bluff plate set at 0 mm above the ground.

Nozzle height (mm)	250	500
Mean deposit (µg cm^{-2})	5.3	5.8

The CRAOV of the log (ln) data revealed that there were no significant differences between the treatments (P=0.05).

Table 7. Mean fluorescent pigment deposits on vertical artificial targets sprayed with a bluff plate sprayer using slotted rotary drum atomizers at different rotational speeds.

Drum rotational speed (Rev min^{-1})	Quantity of pigment deposited (µg cm^{-2})
7100	1.69
6480	1.61
5500	1.88
4450	1.75
3500	1.62

Analysis of variance (P=0.05) revealed no significant differences in pigment deposit between the treatments.

Victorian work also confirmed earlier work with the simple bluff plate (Furness 1991), that the wedge shaped bluff plate can also be used with minimal drift, even with fine droplets and in windy conditions.

These results suggest that bluff plate technology may enable higher work rates, lower chemical rates, lower spraying costs, spraying in high wind conditions, and better spray timing, all of which should improve efficacy, yield and quality, and reduce production costs in growing field crops, especially over large areas. However, this needs to be established with deposit studies on natural targets and efficacy studies with agricultural chemicals for the control of weeds, insect pests and plant diseases, and for the application of foliar nutrients.

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