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Air-tower sprayers increase spray application efficiency in mature citrus trees

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Summary. Conventional pesticide spraying in citrus crops with low-profile sprayers results in pest management problems because of the poor distribution of pesticide throughout the tree. Pesticide losses, particularly drift, are a concern with this type of sprayer especially in orchards situated in or near urban areas.

The spray deposit on citrus leaves and fruit and off-target losses (canopy run-off and drift) were determined for air-assisted low-profile sprayers and air-assisted sprayers fitted with tower air conveyors (air-towers).

The air-tower sprayers produced even distribution of leaf spray deposits through the full height of the tree canopy while the low-profile sprayers produced decreasing leaf spray deposits with increasing height in the trees. The Metters tower sprayer and Cropliner low-profile sprayer resulted in increasing deposits from the 0° axis through to the 90° axis to sprayer travel while the Barlow tower sprayer and the Hardi low-profile sprayer produced a more even distribution of deposits through the axes to sprayer travel. Fruit deposits were not significantly different between sprayers. The Barlow tower sprayer produced significantly less canopy spray run-off compared with the low-profile sprayers. The Barlow tower sprayer resulted in a significant reduction in spray drift in the above tree zone compared with the Hardi low-profile sprayer.

Better distribution of pesticides in citrus tree canopies will improve pest control especially in the top sections of the tree as this is where the greatest increase in pesticide deposit is achieved with air-tower sprayers. Both ground and air contamination from pesticides can also be reduced by using sprayers fitted with air-tower conveyors designed to produce even airflows for the full height of the citrus trees being sprayed.

Introduction

In the Australian citrus industry most insecticide and fungicide applications are currently applied using either low-profile air-blast orchard sprayers or oscillating boom sprayers.

Low-profile air-blast orchard sprayers use medium spray volumes (2–7000 L/ha ; Beattie *et al*. 1989) and do not produce uniform coverage throughout citrus tree canopies, with the major deficiency being low levels of pesticide coverage in the top of trees (Carman 1977; Chapman *et al*. 1981). The poor deposition in the tops of canopies is related to the distance the air must flow from the fan to the top of the tree and the large amounts of leaf, fruit and twigs that filter droplets out of the airflow before it reaches the top of the tree (Carman 1977). Even when the air volume available from the low-profile sprayers is sufficient to displace the air held within the tree canopy (Beasley *et al*. 1976), the movement of this air can still be significantly impeded by citrus tree canopies (Juste *et al*. 1990).

Oscillating boom sprayers provide better coverage than air-blast sprayers (Chapman *et al*. 1981) and provide adequate control of pests and diseases, especially scale insects (Furness and Pinczewski 1985). However, oscillating boom sprayers are expensive to purchase, operate and maintain. They operate at high spray volumes (>7000 L/ha; Beattie *et al*. 1989) in order to produce large droplets to penetrate foliage (Furness and Pinczewski 1985).

Air-tower sprayers have the potential to overcome the coverage problems associated with low-profile air-blast sprayers (Chapman *et al*. 1981) and the operating cost and high application volume problems of the oscillating boom. Sprayers with air-tower conveyors have the structural advantage of greater height overcoming the coverage deficiencies of low-profile air-blast sprayers (Carman 1977). A trial on Californian citrus found that an air-tower sprayer, operating at 20% lower application volume, produced spray coverage in citrus equal to an oscillating boom sprayer (Carman 1977). Air-tower

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Figure 1. Sprayers evaluated in the trial. Air-tower sprayers are: (*a*) Hardi airblast TE 2082 with Barlow tower; (*b*) Metters airblast with fibreglass tower. Low-profile sprayers are: (*c*) Cropliner airblast QP 820 SV; (*d*) Hardi airblast TE 1582.

Table 1. Spraying configuration and operating parameters for each sprayer

Sprayer	Nozzle orifice (mm)	No. of nozzles per side	Operating pressure (bar)	Droplet size (µm)	Droplets <72 µm	Air volume (m^3/s)	Tractor speed (km/h)	Application volume (L/ha)
			Low-profile sprayers					
Cropliner QP 820	1.2	10	15	129	26%	8.8	1.45	1435
Hardi TE 1582	1.5	10	20	131	25%	15.7	2.30	1393
			Tower sprayers					
Barlow sprayer	1.5	14	20	131	25%	14.5	3.33	1365
Metters sprayer	1.2	21	10	136	22%	9.6	2.61	1379

sprayers can produce suitable coverage over a range of application volumes due to the use of an airflow as the carrier of the droplets.

This paper describes an experiment in which the application efficiencies of low-profile air-blast sprayers and air-tower sprayers were compared in terms of evenness of distribution of spray deposits within the tree canopy, canopy run-off and drift.

Materials and methods

Experimental site and sprayers

The field experiment was conducted in a commercial citrus orchard at Gatton (27°34'S, 152°17'E), Lockyer Valley, Queensland, on 19 July 1993. Mature Valencia orange trees planted on a 6.92 by 6.92 m square grid were used. Individual trees were 5 m in height and 5 m wide and pruned to produce rows that ran east–west. The citrus trees had a leaf area index (LAI) of 4.2 measured by a light infiltration method (Cunningham and Harden 1998; Lang 1987). The sprayers (Fig. 1) used were 2 low-profile airblast sprayers (Cropliner QP 820 SV and Hardi TE 1582) and 2 airblast sprayers fitted with air-tower conveyors. The first air-tower sprayer was a Hardi TE 2082 fitted with a 5.1 m aluminium Barlow tower and the second air-tower sprayer was a Metters sprayer fitted with a 3.6 m fibreglass tower. The Metters tower was shorter than the Barlow tower but directed air from the top of the tower upwards at about 45° into the tops of the trees. The configurations required for each sprayer to operate at an application volume of 1400 L/ha are shown in Table 1. The sprayers were equipped with Albuz (Ceramiques Techniques Desmarquest - Evreux, France) sintered-alumina, hollow-cone nozzles that were operated at pressures that maintained a droplet volume median diameter in the range 129–136 µm (Table 1). The droplet spectra produced by each nozzle was measured on a Malvern 2600 laser diffraction droplet analyser (Malvern Instruments Ltd). The speed and volume of the airflows produced by each sprayer were measured using a Davis electronic wind speed indicator (Davis Instruments). Tractor speeds were selected for each sprayer to produce a uniform volume of airflow being introduced to the citrus trees by each sprayer (Table 1). The formulae for this calculation involved dividing the airflow produced by the sprayer by the cross-sectional area of the trees being sprayed. The cross-sectional area was calculated as tree canopy height by width for single side sprayers and 2 times tree canopy height by width for double side sprayers.

All sprayers were operated on the same day and sample rows of trees were sprayed from both sides in accordance with commercial practice. Only the side of the low profile facing the sample row of trees was operated. Two guard rows of trees were left between sample rows and 5 guard trees were left between sample trees in a row or the end of the row.

The environmental conditions during spraying were: air temperature of 23–29°C, relative humidity of 50–80% and a south-easterly wind at 2–7 km/h.

Leaf spray retention

A measurement of the spray deposition on leaves and fruit is required for the assessment of spray machinery when considering protectant fungicide, miticide and scale insect control applications in citrus. A fluorescent dye was used as the tracer for analysis of spray deposits (Ciba-Geigy 1985). A suspension of Helios 500 SC dye (0.0035% formulation v/v; Ciba Ltd, Switzerland) and a non-ionic surfactant [Agral (ICI Australia) at 0.01% v/v] was applied at a target volume of 1400 L/ha. The trees were allowed to dry and single leaves were collected from 18 positions (Whitney *et al*. 1989) on each of 3 trees per treatment. Collection positions were chosen at 3 heights (bottom, 1.4 m; middle, 3.0 m; top, 4.6 m), at 3 axes through the tree (0°, 45° and 90° relative to sprayer travel) and at 2 canopy positions (outer and inner) (Fig. 2). Individual leaves were placed in 125 mL glass bottles and washed by shaking the bottles after adding 10 mL of ethyldigol to recover the dye. Unsprayed leaves were included in the sampling to test for any background fluorescence from pesticides. The resultant solution was measured on a single-beam Sequoia-Turner Model 450 Digital Fluorometer (Sequoia-Turner Corporation) (excitation wavelength 340–370 nm, emission wavelength 430–500 nm).

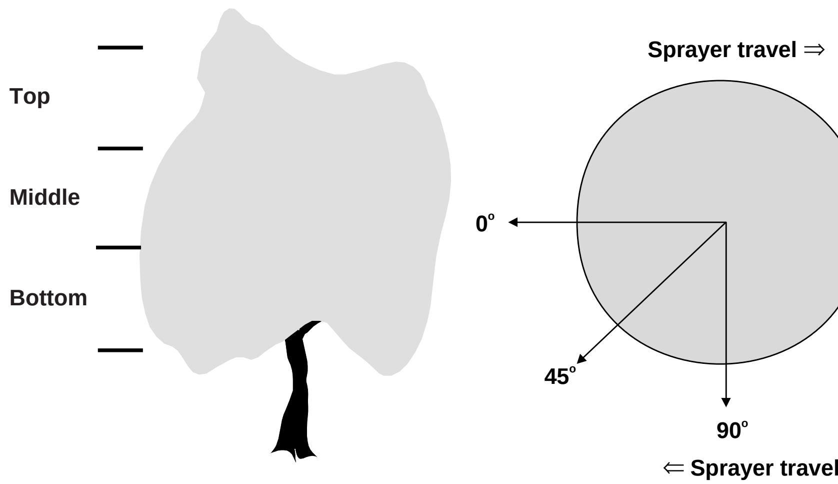

Figure 2. Tree height zones and tree axis zones used in leaf and fruit sampling.

The surface area for each leaf was estimated to calculate dye recovery per unit area of leaf by weighing unwashed leaves and then measuring a subsample with an optical image analyser to produce a surface-area-to-weight relationship ($r^2 = 0.93$, $P<0.001$).

Fruit spray retention

After spraying, the fruit were allowed to dry and then marked for orientation to spray direction. Single fruit were collected from the standard 18 sampling sites on each of 12 trees. The fruit were measured for diameter on 2 axes to calculate fruit surface area, cut into front and back halves, placed in plastic bags and washed with 20 mL of ethyldigol to recover the dye. Unsprayed fruit were included in the sampling to test for any background fluorescence from pesticides or interference from fruit juices. The resultant solution was measured as above.

Canopy spray run-off

Filter papers were positioned beneath the sample trees on timber strips to sample spray run-off. The timber strips were placed under each tree at 3 axes (0°, 45° and 90° to sprayer travel) and filter paper collectors (Whatman No. 4, 100 x 25 mm targets) were located at six, 0.5 m intervals along the strip from the trunk to the canopy edge to give 18 run-off collectors per tree. The filter papers were allowed to dry and placed in 125 mL glass bottles. The filter paper samples were washed with 10 mL of ethyldigol for dye recovery and the resultant solution measured as above.

Spray drift

The spray drift measurements were made with a low-profile sprayer (Hardi) and an air-tower sprayer (Barlow tower sprayer) operating simultaneously on a target row of citrus trees. The citrus trees were the same size and had the same LAI as described above. Each sprayer sprayed both sides of the target row with the low-profile sprayer having only the nozzles on one side operating. Two replicates for drift measurement were conducted, each replicate consisting of 3 consecutive spray runs by each sprayer, to produce drift deposits in a measurable range.

Spray drift was measured using lengths of 1 mm copper wire suspended from the top of 15 m perpendicular towers to the ground to act as collectors for small droplets. A drift tower was situated 35 m downwind of each sprayer with 5 rows of citrus trees between them. Two 15 m lengths of copper wire per tower were used and following the spray runs the copper wire was divided into 1 m lengths and washed with 10 mL ethyldigol to recover the dye. The resultant solution was measured as above. The drift data were divided into a lower zone for drift losses below the tree top and an upper zone for drift losses above the tree top.

The environmental conditions during spraying were: air temperature of 29°C, relative humidity of 50%, and a south-easterly wind at 5 km/h.

Experimental design and statistical analysis

The retention and run-off experiment was a replicated complete block design with 4 sprayer type treatments and 3 replications. The leaf, fruit and run-off data were converted to a natural log transformation and examined using 2-way analysis of variance. The drift experiment involved only 2 sprayer types and this data were analysed by a paired *t*-test. The data were analysed using the Minitab statistical package. Treatment means presented in tables and figures are back-transformed data.

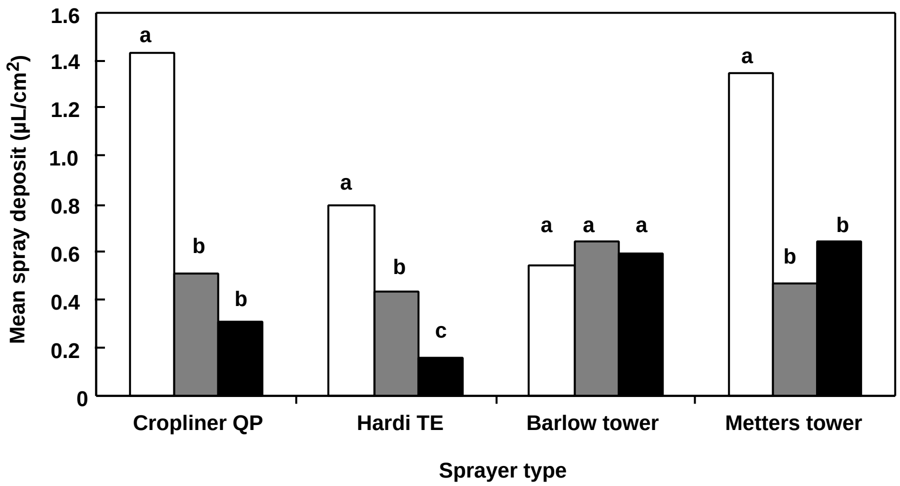

Figure 3. Mean spray deposit on leaves (µL/cm^2) for each sprayer through tree height zones (open bars, bottom; shaded bars, middle; closed bars, top). Bars with the same letter are not significantly different at $P = 0.05$.

Results

Leaf spray retention

The Hardi low-profile sprayer resulted in decreasing leaf deposits with increasing height in the tree (Fig. 3). The Barlow tower sprayer produced uniform leaf deposits throughout the tree height zones. The Cropliner low-profile sprayer and the Metters tower sprayer had uniform leaf deposits in the middle and top tree zones and greater leaf deposits in the bottom tree height zone (Fig. 3). In the bottom tree zone the Cropliner low-profile sprayer and the Metters tower sprayer produced the highest leaf deposits while in the middle tree zone there were no differences in leaf deposits produced by different sprayers. In the top tree zone both the tower sprayers produced significantly ($P<0.05$) more spray deposit compared with the low-profile sprayers (Fig. 4).

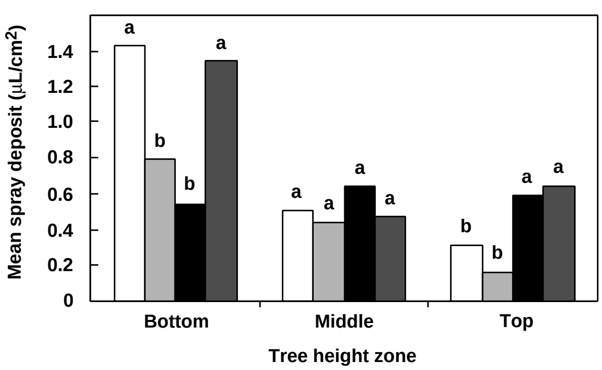

Figure 4. Mean spray deposit on leaves (µL/cm^2) in tree height zones for each sprayer (open bars, Cropliner QP; lightly shaded bars, HardiTE; solid bars, Barlow tower; heavily shaded bars, Metters tower). Bars with the same letter are not significantly different at $P = 0.05$.

The Hardi low-profile sprayer had equal leaf deposits through the 3 axes to sprayer travel (Table 2). The Barlow tower sprayer had less deposit at the 0° axis compared with the 45° and the 90° axis. The Cropliner low-profile sprayer and the Metters tower sprayer showed a trend of increasing leaf deposits from the 0° axis to the 90° axis to sprayer travel (Table 2). Leaves in the outer canopy had significantly ($P<0.001$) greater deposits (0.737 µL/cm^2) than leaves in the inner canopy (0.511 µL/cm^2).

Fruit spray retention

Sprayers did not produce significantly different mean fruit spray deposits. Fruit spray deposits were greater ($P<0.01$) in the bottom height zone (0.825 µL/cm^2) compared with the middle (0.614 µL/cm^2) and top

Table 2. Mean spray deposit on leaves (µL/cm^2) for sprayers through tree axes

Means within each column followed by the same letter are not significantly different at $P = 0.05$

Tree axis to sprayer travel	Cropliner QP	Hardi TE	Barlow tower	Metters tower
90°	1.031a	0.462a	0.718a	1.152a
45°	0.775b	0.438a	0.628a	0.752b
0°	0.333c	0.417a	0.440b	0.506c

Table 3. Mean canopy spray run-off from all locations (μL/cm^2) for each sprayer

Means followed by the same letter are not significantly different at P = 0.05

Sprayer	Canopy spray run-off
Low-profile sprayers	
Cropliner QP 820	0.827a
Hardi TE 1582	0.346b
Tower sprayers	
Barlow sprayer	0.085c
Metters sprayer	0.692a

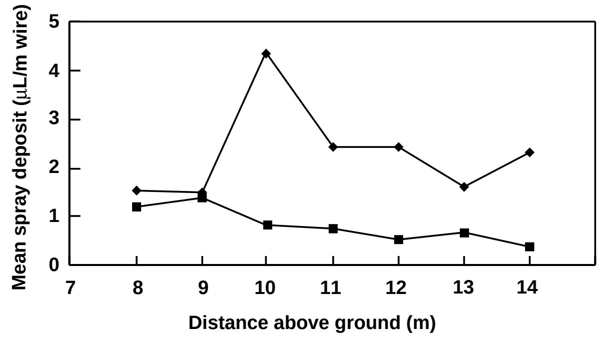

Figure 5. Spray drift losses in the above tree height zone for Hardi TE low-profile sprayer (◆) and Barlow tower sprayer (■). The means of spray drift for each sprayer are significantly different (n = 7, P<0.01).

height zone (0.498 μL/cm^2) of the tree. There was less (P<0.05) spray deposit on fruit from the 0° axis (0.536 μL/cm^2) compared with the 45° (0.684 μL/cm^2) and the 90° axis (0.707 μL/cm^2) to sprayer travel. The spray deposit on the front half of the fruit (0.769 μL/cm^2) was greater (P<0.001) than the deposits on the back half of the fruit (0.521 μL/cm^2).

Canopy spray run-off

The Barlow tower sprayer had the least (P<0.05) canopy spray run-off of all the sprayers. The Hardi low-profile sprayer produced greater run-off than the Barlow tower sprayer with the Cropliner low-profile sprayer and the Metters tower sprayer producing the greatest (P<0.05) amount of run-off (Table 3). Canopy spray run-off showed a trend (P = 0.058) of increasing from the 0° axis to the 90° axis to sprayer travel.

Spray drift

There was no significant difference between sprayers in the drift produced in the tree height zone (0–7 m above ground). The Barlow tower sprayer produced significantly (P<0.01) less spray drift (Fig. 5) than the Hardi low-profile sprayer in the above tree height zone (8–14 m above ground).

Discussion

The use of air-tower sprayers improved the uniformity of spray deposit on leaves through the height zones of the tree canopy with the Barlow tower sprayer having the most uniform distribution. This improvement in spray deposit was particularly evident in the top height zone with the air-tower sprayers producing 2–4 times the level of spray deposit compared with the low-profile sprayers. The low-profile sprayers do not provide a sufficient column of air moving into the upper tree canopy and droplets fail to reach leaf targets in this area (Matthews 1992). High proportions of droplets aimed at the upper tree canopy are actually deflected upwards and contribute to spray drift. The air velocity is lower in the top of the tree canopy due to the distance air must move from the low-profile sprayer and this reduces the impaction efficiency of any droplets that do reach this section of the tree (Hislop 1991). Improved spray deposits, from the air-tower sprayers, in the top height zone would result in improved pest management as this area of the tree canopy is a common site for insect pest and plant disease outbreaks. The leaf spray deposit in tree axes zones showed the Hardi low-profile sprayer and Barlow tower sprayer to have the most uniform deposit pattern. The greater spray deposit on outer leaves compared with inner leaves in the canopy is a predictable pattern related to the protected nature of inner leaves (Salyani and McCoy 1989; Whitney *et al*. 1989). The Barlow tower sprayer had the most uniform spray pattern considering deposits in all canopy zones in terms of both height and axis. The improvement in uniformity in spray deposits and reduction in canopy run-off from the Barlow tower sprayer compared with the Metters tower sprayer results from internal vanes inside the Barlow tower producing more even partitioning of the airflow through the tower and into the tree canopy.

There were significant differences in leaf spray deposits between the 2 low-profile sprayers with the Hardi sprayer producing more uniform spray deposits through the tree axes than the Cropliner sprayer but producing lower spray deposits in the bottom tree zone. These differences are a result of the differences in air velocities generated by each sprayer. Although the air volume used by each sprayer in the spraying of the trees was made uniform by adjusting tractor speed there were still differences in the measured air velocity at the fan for each sprayer. The Hardi sprayer had an average air velocity of 45 m/s while the Cropliner sprayer had an average air velocity of 32 m/s. The greater air velocity of the Hardi sprayer resulted in greater penetration of the tree canopy but reduced the amount of spray retained on leaves in the bottom tree zone that was closer to the fan. The greater air velocity did not improve spray deposition in the upper tree canopy due to the acute angle the airflow met the tree canopy.

Equal spray deposits on fruit from each sprayer were due to the exposed position of the fruit in the tree canopy and indicates that citrus fruit are an easier target for spray coverage than leaves in a citrus tree canopy.

The canopy spray run-off recorded for each sprayer shows a direct correlation (r^2 = 0.99, P<0.01) with the leaf deposit level in the bottom tree height zone. This indicates that over-spraying the bottom section of trees is the main cause of losses of pesticide as canopy run-off. The Cropliner low-profile sprayer and the Metters tower sprayer produced high deposits in the low tree zone and as a result had high canopy run-off losses. The Hardi low-profile sprayer produced lower canopy run-off than the Cropliner low-profile sprayer and the Metters tower sprayer but this is due to higher velocity air carrying spray through the bottom tree zone. Even though the spray was not lost as canopy run-off it will be lost out the other side of the tree and still be off-target loss. The Barlow tower sprayer distributed the air flow more evenly throughout the tree canopy and reduced the canopy run-off losses significantly. The trend of greater canopy run-off from the 0° axis to the 90° axis to sprayer travel is most probably an effect of tree canopy resistance to air flow during spraying.

The Barlow tower sprayer reduced spray drift above the canopy and this would relate to benefits such as reduced environmental contamination by using air-tower sprayers. The reduced spray drift results from an airflow that carries droplets into the tree in a horizontal plane thereby minimising the movement of droplets in an upward direction. The low-profile sprayers produce air flow in an upward direction and a proportion of this airflow deflects around the upper section of the tree canopy and carries spray droplets above the tree canopy.

Air-assisted sprayers with tower air conveyors that evenly partition airflow have the advantages of more even distribution of air and pesticide throughout the tree canopy and reduced loss of pesticide as canopy run-off and drift.

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