Comparison of conventional medium to high-volume and high-volume sprayers with a low-volume sprayer for the control of Black Spot, *Guignardia citricarpa* Keily, on Valencia Orange

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Summary
Conventional air-blast (medium to high-volume) and oscillating boom (high-volume) sprayers were compared with a low-volume sprayer, with four fan-assisted rotary cage drum atomiser spray heads mounted on a vertical tower, for the control of black spot, *Guignardia citricarpa* Keily, on Valencia orange, *Citrus sinensis* (L.) Osbeck. The sprayers were used to apply fungicides at a standard rate per hectare. Significantly ($P<0.05$) more unmarketable fruit were produced by trees sprayed with the low-volume sprayer than by trees sprayed with the other sprayers. This difference was attributed to variable deposition of the fungicide sprays and spray volume.

Introduction
Black spot, *Guignardia citricarpa* Keily, is a serious fungal disease of Valencia orange, *Citrus sinensis* (L.) Osbeck, in coastal New South Wales (Keily 1949). The disease affects fruit at or near maturity leading to blemish and decrease in yield from increased fruit drop. Copper-based sprays followed by a benomyl spray are recommended for its control (Scott 1982). The concentrations recommended for these fungicides are based on dilute medium-volume (MV) to high-volume (HV) sprays applied with conventional air-blast (AB) and oscillating boom (OB) sprayers. OB sprayers are more effective than AB sprayers but both types are wasteful and costly to operate (Furness and Pinczewski 1985). This has led to the development of low-volume (LV) sprayers, with multiple fan-assisted rotary atomiser (FARA) spray heads mounted on vertical towers, to reduce costs associated with pest, disease and nutrient disorders. We define low, medium and high-volume sprays as <2000, 2-7000 and >7000 L ha^{-1}, respectively, for 3 to 4 m high citrus trees planted in rows 6 m apart.

We compared a LV FARA sprayer with a medium to high-volume (M-HV) AB sprayer and a HV OB sprayer for the control of black spot. The sprayer we chose for the experiment was a Micro-spray (Micro-spray (Australia) Pty Ltd) sprayer, one of three LV FARA sprayers available in Australia at the time of the experiment in 1981. The other two sprayers were the Mister Miser (Waikerie Co-operative Producers Ltd) and the Span Sprayer (Patterson Engineering Pty Ltd). Distribution of spray on trees sprayed by the Mister Miser sprayer has been studied (Furness and Pinczewski 1985) but no information has been published on the effectiveness of any of the three sprayers for the control of citrus pests and diseases.

Materials and methods
The experiment was conducted in a commercial orchard at Somersby (33°55'S., 151°19'E.), New South Wales, using a 26-row rectangular block of 754 Valencia orange trees on *Poncirus trifoliata* (L.) Raf. rootstocks. The trees were 15-years old, 3 to 4 m high and planted on a 3 by 6 m grid. The rows ran directly east-west.

The experiment was designed as a randomised complete block with five replicates for each of the four treatments detailed in Table 1. The 20 plots were allocated to seven of the 26 rows and each plot consisted of nine to 10 consecutive trees. The second row from the southern end of the block was the first treatment row; the northern-most treatment row was adjacent to a block of navel oranges which were not sprayed. The other treatment rows were separated by three buffer rows. Each buffer row was sprayed for black spot using the HV OB sprayer with a horizontal outrigger.

The HV OB sprayer was operated at 2.3 km h^{-1}, 2800 kPa and 60-70 oscillations min^{-1}.

The M-HV AB sprayer (Tornado), was operated at 1.8 km h^{-1}, and 3100 kPa with the nozzles operating on one side only.

The LV FARA Micro-spray TT1200 sprayer was operated with four Micronair AU3000 fan-assisted rotary drum atomiser spray heads mounted on a vertical tower. In the vertical plane, the heads were directed towards the ground at an angle of 10-15° below horizontal. The heads were directed backwards at about 25° from a right angle taken from the spray vat. This 'divergent head' configuration was similar to that recommended by the manufacturer. The sprayer was operated at 2.4-3.2 km h^{-1}, 200-275 kPa, variable restrictor unit setting 3, and a rotary atomiser and fan speed of 6000 rpm. The output of each head was standardised before the experiment commenced. The sprayers travelled from east to west on the northern side and west to east on the southern side of each row. Pre- and post-spray spray tank volumes were measured using gauges and buckets.

The four central trees in each plot were assessed. The number of fruit dropped was counted on 1 December 1982 and the fruits on each tree in mid January 1983 were harvested, counted, weighed and graded either

Table 1 Treatments and rates of fungicides applied

Treatment	Volume of spray (L ha^{-1})	Fungicide (kg ai ha^{-1} or 100 L^{-1})					
		Cupric hydroxide				Benomyl	
		27 Oct 1981		16 Dec 1981		16 Feb 1982	
		ha^{-1}	100 L^{-1}	ha^{-1}	100 L^{-1}	ha^{-1}	100 L^{-1}
Unsprayed	0	0	0	0	0	0	0
High-volume oscillating boom[A]	9000	9.6	0.11	9.6	0.11	2.3	0.025
Medium to high-volume Tornado	6750[C]	14.4[C]	0.21	-	-	-	-
air-blast[A]	4500	-	-	9.6	0.21	2.3	0.050
Low-volume fan-assisted rotary atomiser Micro-spray TT1200[B]	500-670	9.6	1.43	7.2	1.44	2.3	0.453

[A] 250 ml 10 L^{-1} petroleum spray oil added to vat on each occasion.
[B] 50 ml non-ionic surfactant (Agral 60) added to vat on each occasion.
[C] Higher than prescribed rate of 4500 L ha^{-1} (see text).

Table 2 Treatment means for fruit number, fruit weight, unmarketable fruit, fallen fruit and copper and benomyl residues. Means followed by different letters are significantly different (P<0.05)

Treatment	Number of harvested fruit(log)	Fruit weight (log kg)	Number of un marketable (logx+1)	Number of fallen fruit (logx+1)	Residues		
					Cu (ppm)	benomyl (μg cm^{-2} leaf) 0.0-2 m above ground level	benomyl (μg cm^{-2} leaf) tree apex
Unsprayed	2.60a	1.60a	1.68a	2.40a	-	-	-
High-volume oscillating boom	2.54a	1.61a	0.05b	1.46b	44.4a	1.28a	1.56a
Medium to high-volume Tornado air-blast	2.52a	1.65a	0.08b	1.53b	66.4b	1.57a	1.07a
Low-volume fan-assisted rotary atomiserMicro-spray TT1200	2.63a	1.67a	0.54c	1.70b	42.4a	1.36a	1.71a
s.e. of mean	0.08	0.07	0.12	0.10	3.6[A]	0.10	0.18

[A]Pooled s.e.

as marketable or unmarketable as fresh fruit according to State regulations (NSW Plant Diseases Act 1924, as amended).

Residues of cupric hydroxide on mature leaves were determined 1 day after the second spray. A sample of 75 leaves was picked from the assessment trees in each sprayed plot. They were picked non-selectively between 0.5 and 2 m above ground height. Each set of leaves was washed thoroughly in a solution of 15 ml 1M HCl in 500 ml distiled water containing 0.05 g sodium lauryl sulphate. The washings were diluted 1/50 with distiled water and the concentration of copper determined by atomic absorption spectrophotometry.

Residues of benomyl were determined on leaves sampled 5 days after spraying. Two assessments were made; the first for 15 leaves picked non-selectively between 0.5 and 2 m above ground height around each of three assessment trees in four replicates from each sprayed treatment and the second for 50 leaves picked non-selectively from the apex of one assessment tree from each of two sprayed replicates per treatment. Leaves were individually washed with chloroform and 50 ml 0.1M HCl and the chloroform evaporated in a steam bath. The acid extract was filtered through a glass wool plug, adjusted to a standard volume and absorbance measured against 0.1M HCl using ultraviolet spectroscopy. The quantity of benomyl was calculated as: muroprans benomyl = A281 - A300 x final volume x 11.2 x 1.52, where A281 = absorbance of carbendazim produced, A300 = reference reading, 11.2 = factor from calibration graph and 1.52 = conversion factor for carbendazim to benomyl.

The surface area of each leaf was determined.

The numbers of fruit, weight of fruit, numbers of unmarketable and fallen fruit were transformed to logs (base 10) and analysed using two-way analysis of variance. Copper residues from the three spray treatments were compared (pairwise) by the t-test for unequal variances; benomyl residues were analysed by one-way analysis of variance (Steel and Torrie 1960).

Results and discussion

The number of harvested fruit and mean fruit weight were not affected by the treatments (Table 2). Significantly ($P<0.05$) more unmarketable fruit were produced by trees sprayed with the LV FARA sprayer, than by trees sprayed with the conventional M-HV AB and HV OB sprayers; all sprayed trees produced significantly less unmarketable fruit than the unsprayed trees (Table 2). The results clearly show that the LV FARA sprayer treatment was ineffective and not as effective as the M-HV and HV sprayer treatments. Better results may have been obtained by the LV FARA sprayer if a higher volume, more dilute, spray had been applied instead of the spray applied in this case. The maximum output of the Micro-spray sprayer with four Micronair TT1200 spray heads is about 2000 L ha^{-1} for 3-4 m high orange trees planted on a 3 by 6 m grid.

The efficacy of the MV spray applied by the M-HV AB sprayer may have been enhanced by the first spray applied by this sprayer on 27 October 1981 (Table 1). About 1.5 times the prescribed volume (4500 L) of spray and weight (9.6 kg ai) of copper hydroxide ha^{-1} was applied. A faulty pressure gauge contributed to this error. This led to a significantly ($P<0.05$) higher residue of copper (about 1.5 times) in this treatment than in the other sprayed treatments (Table 2). This treatment may have been more effective than the LV FARA sprayer treatment but less effective than the OB sprayer treatment had the prescribed amount of copper hydroxide been applied. It was included in the analysis of the data because only one of the three sprays required for effective control of the disease was affected. Its exclusion from the analysis of the data would not affect the validity of the comparison between the number of unmarketable fruit between the other two treatments.

Spray residues from the LV FARA sprayer were very variable compared to the M-HV AB and HV OB sprayers; the standard errors of the individual treatment means between 0.5 and 2 m above ground level were 5.90, 1.86 and 1.12 for copper and 0.17, 0.08, and 0.07 benomyl, for the three sprayers respectively. The variation was consistent with visual observations during the experiment.

The divergent spray head configuration of the LV FARA sprayer contributed to this variation by producing an air stream with little turbulence. Work by Furness and Pinczewski (1985) has led to the development of sprayers with converging FARA spray heads. These sprayers produce more turbulent air streams and more uniform spray deposition than sprayers with diverging FARA heads (Furness and Pinczewski 1985). On this basis, biological evaluation of sprayers with converging FARA spray heads would be expected to give better results than those obtained for the LV FARA sprayer used in this experiment.

The bioefficacy of these sprayers should be evaluated. Effective LV sprayers are required to reduce the wastage and high costs associated with conventional M-HV and HV sprayers.

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