Using Point of First Run-off and Spray Volume in Litres per 100 Metres per Metre of Canopy Height for Setting Pesticide Dose

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ABSTRACT

In Australia, pesticide labels for fruit trees and grapevines are based on the concentration of chemical (amount per 100 litres) for dilute spraying to the point of first run-off. Chemical rate per hectare is regarded as technically flawed and is therefore no longer provided. A simple and practical way to specify spray volume with this new pesticide label format is litres per 100 metres per metre of canopy height (X L 100 m^{-1} m^{-1}). This is also a simple and practical parameter to express dose efficiency, with the advantage that it can be directly related to the amount of pesticide deposited per cm^2 of foliage. If X L 100 m^{-1} m^{-1} is multiplied by 100 the figure obtained is the spray volume applied to one hectare of vertical canopy wall

In citrus, using a multi-fan sprayer, at a spray volume rate of 25 L 100 m^{-1} m^{-1} (1 500 L ha^{-1}), the spray volume deposited per square cm of leaf surface was about 0.7µl cm^{-2} , rising to about 0.9 µl cm^{-2} at 60 L 100 m^{-1} m^{-1}. Above this spray volume, increases in the spray volume deposited were small. This indicates a point of first run-off in the range 50 to 60 L 100 m^{-1} m^{-1} for this sprayer in this orchard.

For concentrate spraying, when a spray volume of 50 L 100 m^{-1} m^{-1} was selected as the point of first run-off, the increase in the predicted mean amount of chemical deposited at 25 L 100 m^{-1} m^{-1} was small. However, when 100 L 100 m^{-1} m^{-1} was selected, the increase was about three times that with dilute spraying at run-off and above. This shows the importance of not using concentrate spraying based on dilute spray volumes that cause excessive run-off, and accurately determining the spray volume at the point of first run-off when attempting concentrate spraying.

There was a small decrease in mean deposition as spraying speed increased from 3 to 6 km h^{-1}, especially from 4 to 6 km h^{-1}.

A preliminary spray coverage trial using a direct blast multi-fan sprayer was also carried out to evaluate the effect of horizontal airstream convergence on spray deposition. Results suggested a slight improvement in spray deposition efficiency and uniformity on citrus trees when compared to that obtained when the same six spray heads were placed in a simple vertical array.

Keywords: Pesticide dose, point of first run-off, distance based calibration, air stream parameters, spray coverage, spray deposition, spray volume, spraying speed, Australia.

1. INTRODUCTION

In orchard spraying, changing flow rate with row spacing changes the dose on the tree. Since the aim of the spraying process is to apply a constant dose per cm^2 of foliage, specifying pesticide rate per ha is, therefore, technically flawed. With hectare based labels and spray calibration, it is also difficult and complicated to handle the parameters of canopy size, foliage density, tree structure, sprayer type and sprayer set up. All these parameters can have a profound influence on the quantity of spray and chemical deposited. For these reasons, the pesticide label format in Australia has been changed, with the label dose expressed as amount per 100 litres sprayed to the point of first run-off (Furness, 2003). For concentrate spraying, the chemical concentration is increased in the same proportion as the spray volume is reduced. In addition, a system of distance based calibration, combined with spray volumes expressed in litres per 100 metres per metre of canopy height, is being introduced (Furness, 2006 a). Some suggested volumes for the point of first run-off are: 15 to 25 L 100 m^{-1} m^{-1} for pome and stone fruit, 25 to 40 for grapevines and 30 to 60 for citrus, although this will vary, depending on a range of factors such as the nature of the target being sprayed, canopy type and density, and sprayer type. Multiplying these values by 100 gives the litres per hectare of vertical canopy wall. Bjugstad and Stensvand, (2002) also reported a change to distance based calibration as a simpler method for dosing three-dimensional crops in Norway. However, there has been no change to the pesticide label format for Norway.

In orchards, the target is a vertical canopy wall sprayed with a vertical swath. In our opinion, this also means that the common practice of normalising spray deposits per hectare to measure spraying efficiency (for example: Pergher and Lacovig, 2005 and Richardson *et al*., 2006), while perhaps the only technique if the label specifies a rate per hectare, is also flawed. A better way to measure spraying efficiency is by relating deposition per cm^2 to the amount of spray delivered by the sprayer to the vertical canopy wall. Again, we propose the canopy wall area unit of 100 metres per metre of canopy height (100 m^2 of vertical canopy wall). This unit also has the added advantage of being directly related to chemical deposition per cm^2 of foliage.

Citrus trees can be large and dense, and pests such as California red scale (Aonidiella aurantii (Maskell)) and various species of mealybugs, as well as plant growth regulators, require very high spray volumes (up to 200 L 100 m^{-1} m^{-1} (10 000 L ha^{-1})), travel speeds around 2 km h^{-1} and very effective spray coverage, including on sheltered, inner canopy foliate (Carman, 1989). In addition, a diverse range of different types of sprayers are used. To account for all these difficulties, some more practical and simple ways of calibrating and determining pesticide dose are desirable.

The low profile design of the standard air-blast sprayer makes it difficult to obtain good uniformity in spray coverage throughout the canopies of fruit trees and produces high spray drift. While adjusting air volume, air velocity and travel speed, can reduce spray drift, it is generally at the expense of spray coverage efficiency and uniformity (Walklate *et al*., 1996 and Cross *et al*., 2003). Leaf shingling (especially at high air velocities) due to the uni-directional nature of the air-blast, deflects air around the canopy thereby reducing spray penetration into the inner canopy (Dibble and Steinke, 1992).

Randall, (1971), and Furness and Pinczewski, (1985) showed that large air volumes, lower air velocity, convergent air flow and air profile matched to the canopy, improve coverage uniformity and dose efficiency in air assisted spray application to fruit trees and grapevines. The work by Randall was important in that air volume was increased at a constant air velocity by increasing the width of the air exit duct. This resulted in increased coverage. In much of the more recent work, air volume has been increased by increasing air velocity (for example Pergher and Lacovig, 2005), and it is probably the velocity increase rather than the volume increase that reduces spray coverage, due to increased leaf shingling. Hence with high volume, high velocity air, statements that deposition is reduced by large air volumes passing through the tree are probably not correct. Rather, the reduced deposition is probably caused by the high velocity component causing leaf shingling, which causes the air and spray to be deflected around, above and below the canopy. Our visual observations support this. Hence further work is needed to clarify the effects of these parameters.

Work on cross flow sprayers, sprayers with flexible ducts to multiple air outlets, double air streams and air bags, for example Holownicki *et al*., (2000), Geva *et al*., (2000), Zande *et al*., (2003), Koch, (2003) and Lakota *et al*., (2003), have further highlighted the importance of air profile, velocity, volume and turbulence; and parameters such as spraying speed and the distance of air outlets to the tree for coverage uniformity, dose efficiency and the reduction of spray drift. However, while effective, ducting and pressurizing air requires high power input or low travel speeds, and the air flow is largely unidirectional.

The history of the development of direct blast multi-fan sprayers, their advantages for reducing power requirements, increasing ground speed and work rate, reducing spray volume and improving dose efficiency when compared to standard air-blast and other orchard sprayers, were demonstrated and reviewed by Furness *et al*., (2003) and Furness *et al*., (2006 a). The importance of fan design with these sprayers for improving coverage and dose efficiency, was also demonstrated by these authors. Field observations of fluorescent pigment deposits at night under black light illumination, also indicated substantial reductions in off target deposition, presumably due to the accurate targeting of air and spray to the canopy and the absence of run-off, but no data was collected.

1.1 Objectives

- To demonstrate the practicality and simplicity of using the point of first run-off, combined with spray volume rates specified as litres per 100 metres per metre of canopy height, as a method for setting pesticide dose, using citrus as an example.
- To further develop the visual droplet rating chart technique as a simple, practical method for determining the volume of spray deposited per cm^2 of foliage.

- To determine the effect of spray volume and spraying speed on spray deposition in citrus.
- To determine the effect of horizontally converging airstreams on coverage uniformity and dose efficiency in citrus with direct blast, multi-fan sprayers.

2. MATERIALS AND METHODS

2.1 Deposition Analysis Techniques

Since pesticide dose on Australian pesticide labels is set by chemical concentration at the point of first run-off, it is important to develop low cost, practical, rapid and simple techniques to determine the point of first run-off that can be widely used throughout the fruit growing and agricultural chemical industries. It is also an advantage if the techniques can be carried out without the need for expensive equipment and specialised expertise.

The spray solution used was SARDI, Yellow Fluorescent Pigment Suspension Concentrate ® (This UV stable fluorescent pigment is manufactured for SARDI by Topline Paint Pty Ltd, Adelaide) at 1 % concentration. The number of droplets impacted cm^{-2} (fine droplets, mean impacted size 250 μ assuming a 2x spread factor) was assessed using a droplet rating chart technique based on visual rating of fluorescence in a dark room under UV-A illumination from a black light (Labino Trac Pac Pro, Solna, Sweden) (Furness *et al*., 2006 b). In that study it was shown that the quantity of spray liquid deposited (μl cm^{-2}) is almost identical to the number of fine droplets deposited cm^{-2} divided by 1000 (calculated from the in air single droplet volume). In addition, in that study, this technique gave chemical deposition values that were within 10 % of a standard chemical residue analysis technique based on Tartrazine. This level of agreement with the Tartrazine analysis is similar to that which would be obtained by comparing different standard chemical residue analysis techniques, so the level of agreement obtained is surprisingly accurate for a visual rating technique. This technique was initially developed from comparisons between the visual droplet rating chart and chemical analysis based on surface scanning of fluorescent deposits of the same pigment using a fluorescence spectrophotometer (Furness and Newton, 1988). We believe that this level of precision is sufficient validation for the simple visual rating chart technique to be used as a standard scientific technique for spray deposition analysis, although further validation by comparison with chemical residue analysis is warranted. Spray coverage results were plotted as fine spots (0.25 mm (250 μ) diameter) on diagrammatic cross sections of citrus trees. Four ratings (each 25 % of the total leaf area) on each leaf were made, and the mean ratings plotted for each tree site from the maximum to the minimum number (Furness *et al*., 2006 b).

2.2 Sampling

Exposed and sheltered leaves (15 leaf samples per site) were sampled from the dense outer canopy. Three heights from the north and south faces of the trees (hedge row planting) were sampled. In the inner canopy 20 leaf samples were taken from two heights. The total number of sites sampled in each tree was 14.

2.3 Sprayers (Figure 1)
Two prototype sprayers, similar to that shown in figure 1 a. (citrus tower sprayers with 4 heads per side) were used. The second sprayer was fitted with 12 heads, six per side. A detailed description of the spray head used is given in Furness *et al*., (2003) and Furness *et al*., (2006 c).

(a)

(b)

(c)

Figure 1. Multi-fan tower sprayers. (a) Commercial citrus tower sprayer with 4 heads per side. (b) Prototype Sprayer showing one of the horizontally converging pairs of spray heads. (c) Prototype sprayer with one pair of horizontally converging spray heads operating, showing the vertical fan pattern produced.

2.4 Treatments

2.4.1 Trial 1: Influence of Spray Volume and Ground Speed on Spray Coverage and Dose

A double sided Quantum Mist citrus tower sprayer with 8 heads and 16 nozzles per head in a simple vertical array was used (figure 1 a.). Nozzles used were Spraying Systems TXVK ceramic tipped, hollow cone. Different nozzle sizes were selected (in a pressure range of 8 to 10 bar to minimize variations in droplet size) to give the flow rate required. The spray volumes applied (L 100 $m^{-1}m^{-1}$) were 25, 46.8, 63.5 and 102 (at 3 km h^{-1}); 24.8 and 58.4 (at 4 km h^{-1}); and 23.8 (at 6 km h^{-1}). A double sided oscillating boom was used for comparison, using a spray volume of 175 L100 $m^{-1}m^{-1}$ at a speed of 2 km h^{-1}. Full details of sprayers used and their specifications are given in Furness *et al.*, (2006 c). The treatments were applied to two trees (two replicates) plus the un-sampled barrier rows either side. Fluorescent pigment solution, as described above, was used. In addition to the leaf samples (sampled as described above), 10 fruit from the outer canopy from each of the north, south, east and west aspects of the tree were also sampled. Droplet ratings were made on the fruit surface and calyx and the volumes deposited estimated (as described above) similarly to leaves.

2.4.2 Trial 2: Horizontal Air Stream Convergence with Three Pairs of Heads (Total of 6 Heads) per Side Compared to Six Heads per Side in a Simple Vertical Array

This was a preliminary experiment only with insufficient replication. It was carried out to determine whether or not further work is warranted. All treatments were applied to two blocks of citrus trees (two replicates) each consisting of three rows x six trees with sampling from the centre two trees in the middle row (two trees per replicate). A double sided sprayer with six heads per side (total of 12 heads) was used. In treatment 1, a simple vertical array of six heads per side was used. In treatment 2, three pairs of heads, converging horizontally at 90 degrees (Figure1 b) were used. Treatment 1 was applied on 2 September 2004 and treatment 2 on 7 September 2004. There was insufficient time and resources to apply and sample all treatments on one day or to duplicate the experiment at another time, but the fact that weather conditions were almost identical on both days almost certainly means that differences due to the different days would be small and no greater than that caused by treatment application at different times on the same day. The trees were five to six metre tall Valencias with a moderate crop of mature fruit. The row spacing was 7.5 m. The canopy density was classified as medium (visual estimate) (Furness *et al*., 2006 a). The spraying speed was 1.5 km h^{-1}. Nozzles used were four Spraying Systems TXVK8 and four SS TXVK 6 ceramic tipped, hollow cone nozzles per spray head. Pump pressure was 8 bar and the flow rate 0.84 (TXVK8) and 0.62 (TXVK6) L min^{-1} per nozzle. This gave a total flow rate of 70 L min^{-1} per row giving a spray volume of 50.9 L 100 m^{-1} m^{-1} (3733 L ha^{-1}). The conditions on both days were almost identical: fine and sunny, temperature 30 – 35° C, RH about 50 %, wind speed averaging about 1 m sec^{-1} from the north/north west (almost calm).

2.4.3 Trial 3: Swath Determination Based on Deposition from a Single Pair of Horizontally Converging Spray Heads

On 15 October 2004, spray was applied to four Navel orange trees on the Loxton Research Centre. Only the middle two trees were sampled. The trees were 3.35 m tall, but skirted to give a canopy wall of 2.85 m. Foliage, due to pruning in the previous season, was very dense (Furness, 2006 a) and there were no fruit on the trees. Row spacing was 7.5 m. The two spray heads were located at a height of 2.09 m above the ground. The airstreams converged horizontally at 90 degrees, but with a 10 degree downward incline from horizontal to match the profile of the canopy (figure 1 c.). The spraying speed was 5.9 km h^{-1}. Nozzles were Albuz red (number 1299-16) ceramic tipped hollow cone, eight jets per head with single sided spraying with the two converging heads. Pump pressure was 11 bar giving a flow rate of 1.875 L min^{-1} per nozzle. Total flow rate was 60 L min^{-1} per row (32 jets) giving a spray volume of 21.4 L 100 $m^{-1}m^{-1}$ (763 L ha^{-1}) (Furness, 2006 b). Conditions were fine and sunny, temperature 15° C, wind 0-1 m sec^{-1} from the south west (almost calm).

To give precision to the swath pattern, sampling more positions was required. Ten leaves per site were sampled. Exposed and sheltered leaves in the outer canopy were sampled from the following height zones (metres): 0.5-0.95, 0.95-1.4, 1.4-1.8, 1.8-2.2, 2.2-2.8 and 2.8-3.35. The mid points of these height zones (metres) were: 0.73, 1.2, 1.6, 2.0, 2.5. and 3.1. From the inner canopy, leaves were sampled from 0.35 m below to 0.35 m above mid points at 0.9, 1.7 and 2.5 m above the ground.

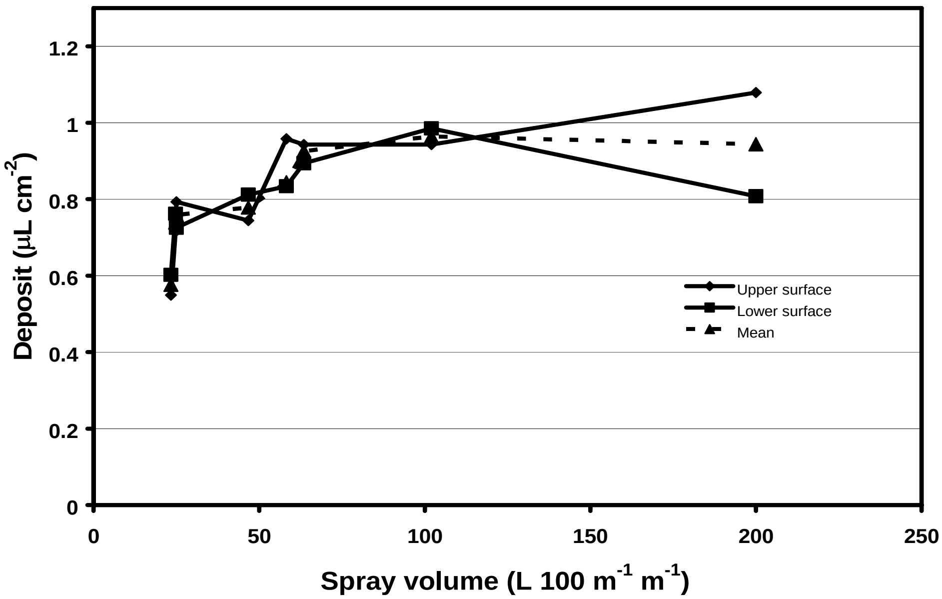
3. RESULTS AND DISCUSSION

3.1 Influence of Spray Volume and Spraying Speed on Spray Coverage and Dose (Trial 1, Figures 2-4)

On leaves, the relationship between the applied spray volume and the volume of liquid deposited is shown in Figure 2 (a). The volume of spray deposited increased rapidly from 25 to 65 L $100m^{-1}m^{-1}$. From 65 to 100 L $100m^{-1}m^{-1}$, the volume of spray deposited remained fairly constant. The value plotted for the spray volume of 200 L $100m^{-1}m^{-1}$ was obtained using a high volume oscillating boom sprayer, and was similar to that obtained for the multi-fan sprayer at 100 L 100 $m^{-1}m^{-1}$, but the oscillating boom was more effective at depositing spray on the upper leaf surface and less effective on the lower leaf surface. The value at 23.8 L $100m^{-1}m^{-1}$ was slightly lower than expected due to the higher travel speed of 6 km h^{-1} (see below). The fitted mathematical expression for the data for the mean deposition, combining upper and lower leaf surfaces and forced through the origin is:

Mean droplet number = 954 * (1 – exp (-0.047 * spray volume).
(R^2 = 0.71)

(a)



(b)

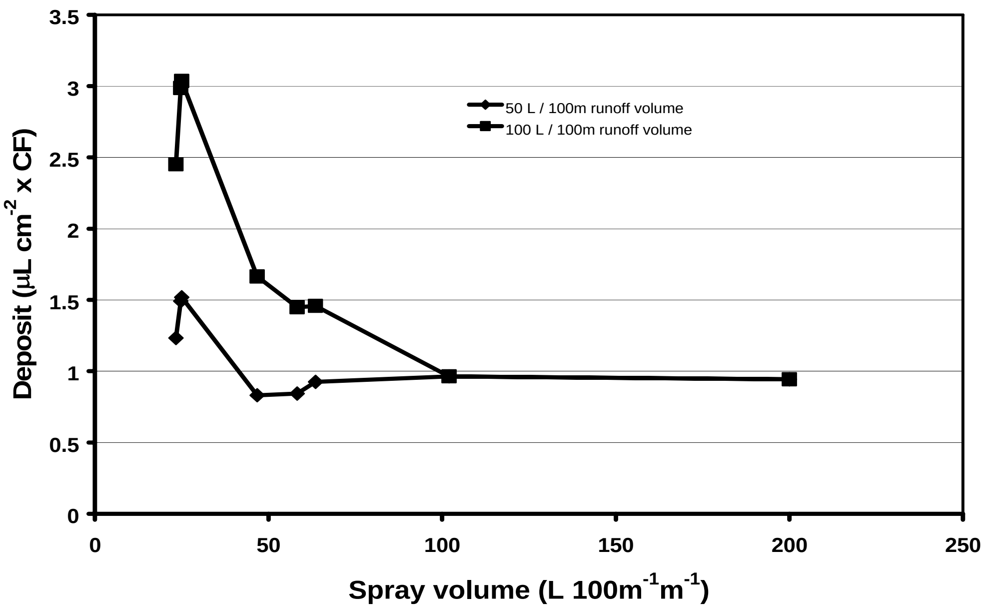


Figure 2. The effect of spray volume on spray deposition on citrus leaves with concentrate spraying. (a) Liquid volume , (b) Estimated relative mean deposit with concentrate spraying using a concentration factor based on a run off volume of 50 L $100m^{-1}m^{-1}$ (diamond points) and 100 L $100m^{-1}m^{-1}$ (square points). Concentration factor above run off volume = 1.

The effect of selecting different wetness volumes as the "point of first run-off" on the estimated amount of chemical deposited with concentrate spraying is shown in figure 2 (b). Multiplying the volume deposited by the concentration factor (CF) gives the relative amount of pesticide that would be deposited when using concentrate spraying. The point of first run off on exposed outer foliage for most crops is about 20 to 30 L $100m^{-1}m^{-1}$ (Furness, 2006 b). When 50 L $100m^{-1}m^{-1}$ was selected as run off for calculating the concentration factor (CF), the relative estimated mean amount of chemical deposited increased only slightly with concentrate application, however, when 100 L $100m^{-1}m^{-1}$ was selected, the relative mean amount of chemical deposited increased dramatically with concentrate spraying, especially at the lower spray volumes. This shows that concentrate spraying should only be attempted when there is minimal run-off with the dilute high volume rate used as the basis for selecting the amount of chemical required. It also shows that concentrate spraying should not be attempted for chemicals that require excessive run-off to achieve acceptable coverage. When the volume used to set pesticide dose causes excessive run-off, run-off still occurs at the lower spray volumes used in concentrate spraying, but the concentration of chemical is higher than that set by the pesticide label, so pesticide residues increase. This also means that the problem increases with increasing concentration factor.

The data also shows that 50 - 60 L $100m^{-1}m^{-1}$ is probably a reasonable value for use as the point of first run-off on dense citrus canopies. It is higher than on most other fruit trees due to the density of the canopy and the need for particularly good spray coverage on this crop.

On fruit, the relationship between the applied spray volume and the spray volume deposited is shown in Figure 3. The relationship is similar to that obtained on the leaves except that the amount deposited is slightly less.

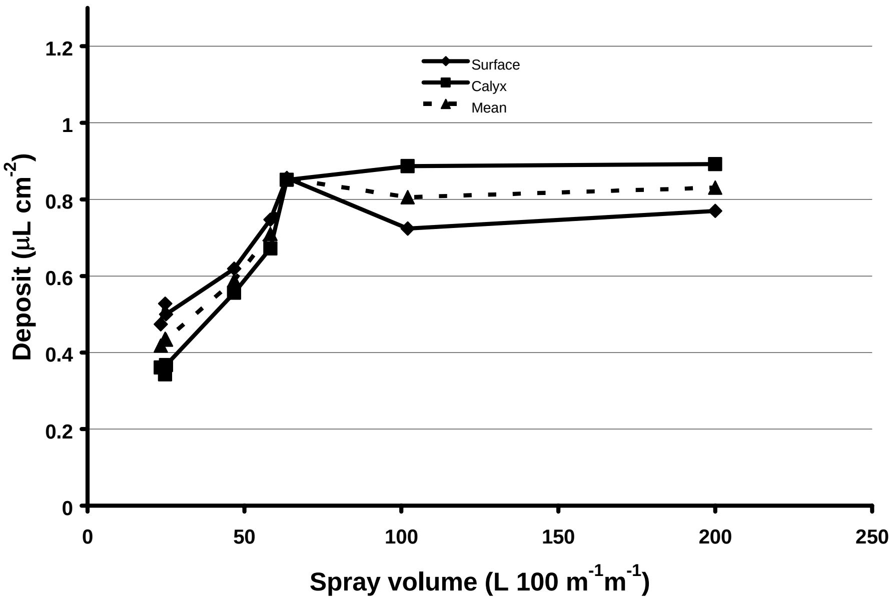


Figure 3. The effect of spray volume on the liquid volume deposited on citrus fruit.

The effect of spraying speed on the amount of spray deposited is shown in Figure 4. The liquid volume deposited fell slightly from about 0.75 μL cm^{-2} to about 0.55 μL cm^{-2} as the spraying speed was increased from 3 to 6 km h^{-1}.

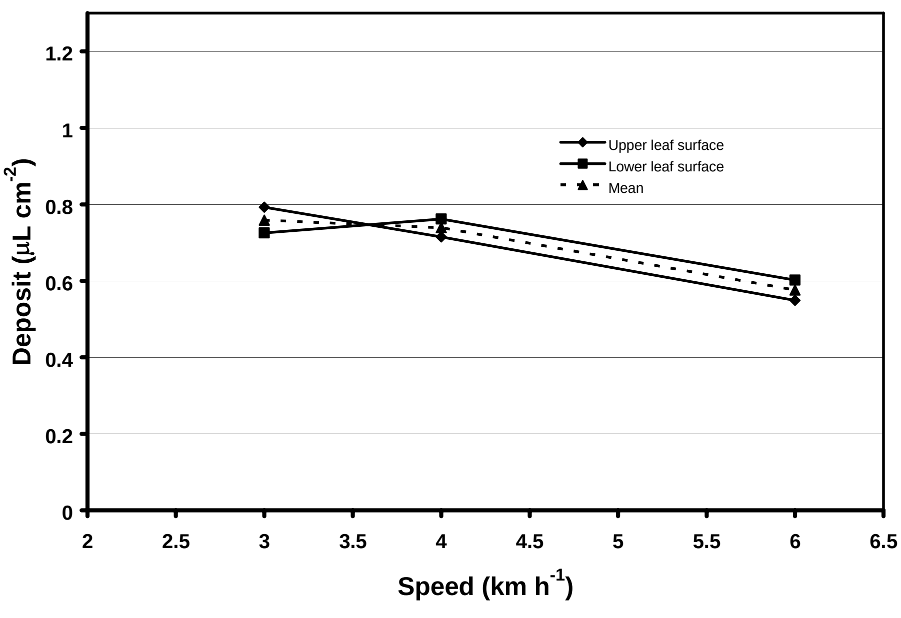


Figure 4. Effect of spraying speed on the liquid volume deposited on citrus leaves using a multi-fan tower sprayer to apply a spray volume of 25 L $100m^{-1}m^{-1}$.

3.1 Comparison of Deposition Volume Between Six Spray Heads in a Simple Vertical Array and Three Pairs of Horizontally Converging Heads (Trial 2, Figure 5)

Spray deposition using horizontally converging pairs of heads was not significantly different to that obtained using heads arranged in a simple vertical array. However, this was a preliminary trial only, and the difference was not quite significant (p=0.059), probably due to insufficient replication. It seems likely that the effect would be significant with more replication. (Furness *et al*., 2006 c) have already shown, that a simple tower array gave better coverage than a standard air-blast sprayer, adequate for full coverage spraying for the control of difficult pests like California red scale (*Aonidiella aurantii* Maskell) and mealybugs (P*seudococcus spp*) (Carman, 1989). Observations suggest that evaluating the effects of horizontal convergence with the heads further apart to increase turbulence closer to the canopy is warranted.

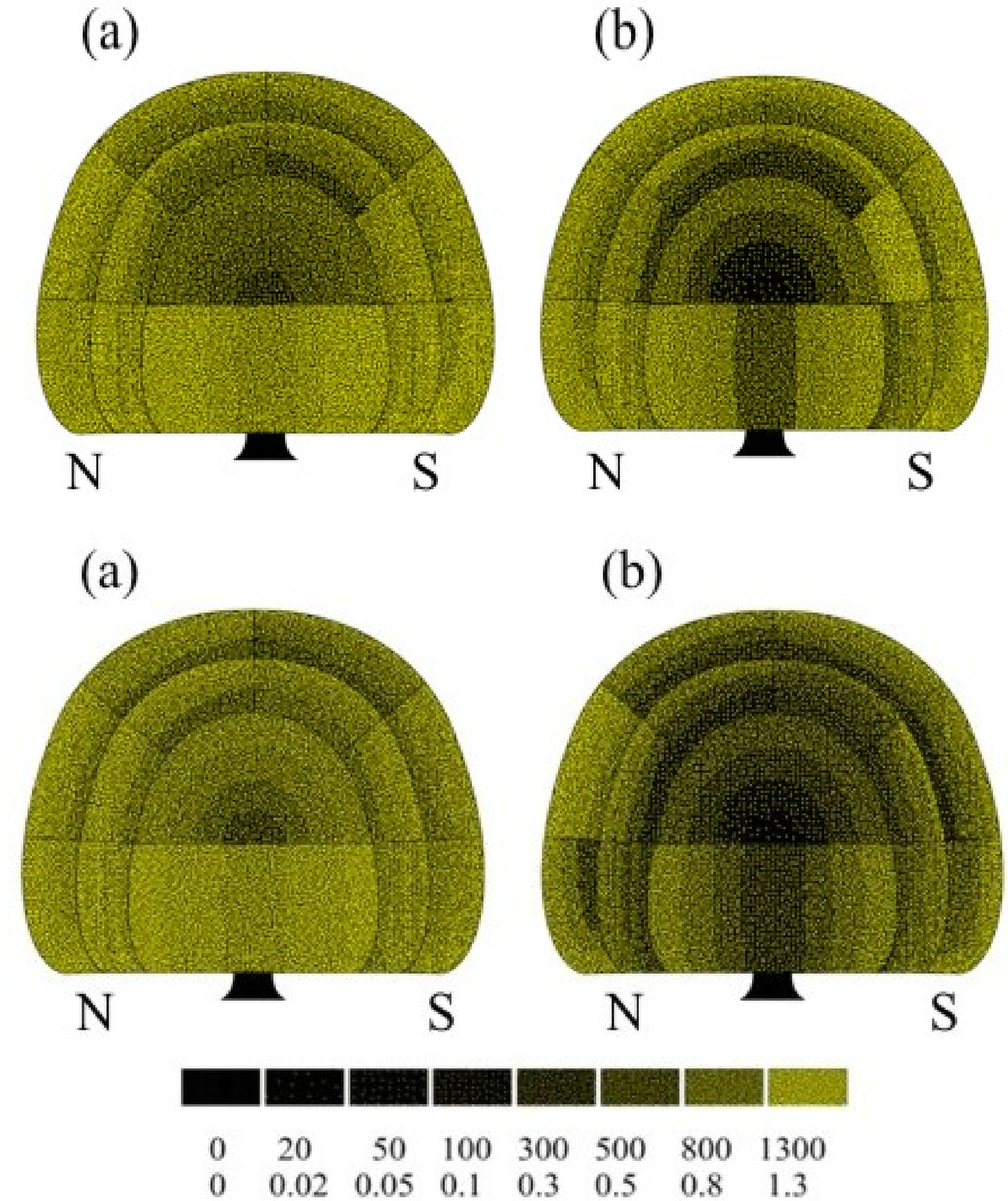


Figure 5. Comparison of droplet deposition on citrus leaves using a multi-fan spray tower with spray heads arranged in 3 horizontally converging pairs (upper diagrams) with a tower with heads in a simple vertical array (lower diagrams). (a) upper leaf surface; (b) lower leaf surface. Bar legend: upper scale – estimated droplet number cm^{-2}; lower scale – estimated deposit volume ($\mu L\ cm^{-2}$).

3.2 Swath Deposition on Citrus Foliage from a Single Pair of Horizontally Converging Spray Heads (Trial 3, Figure 6)

The effective swath (for double overlap of adjacent pairs of heads) of one converging pair of spray heads was about 2 m (Figure 6). In this experiment the convergence angle was 90 degrees. Observations showed that the swath could be varied by changing the convergence angle, the greater the angle the greater the width of the swath produced. Analysis of variance using square root transformation showed a high degree of significance ($p \leq 0.05$) due to leaf surface and to leaf exposure. There were also highly significant interactions ($p \leq 0.05$) for exposure x surface and height x surface. Droplet numbers deposited were greater on exposed than sheltered leaves. Droplet numbers deposited on upper and lower leaf surfaces of exposed leaves was similar whereas on sheltered leaves it was greater on upper than lower leaf surfaces. The location of the swath on the lower leaf surface was slightly higher on the tree than that for the upper leaf surface. It is likely that this is caused by the interactions between the air stream and the foliage. Leaves were observed to rotate (usually 180°) when impacted by the air-blast due to the concave/convex shape of the upper/lower surfaces (respectively). That is the aerodynamically stable convex lower surface orients towards the air stream. The branches were also depressed downwards due to the slight downward incline of the air-blast. The air also had a tendency to be deflected upwards by the dense canopy typical of citrus trees. The upper surfaces were therefore probably sprayed first with the initial air impact, before the air/foliage interactions occurred (which cause most of the deposition on lower leaf surfaces) resulting in a lower height in the position of the swath on upper than lower leaf surfaces.

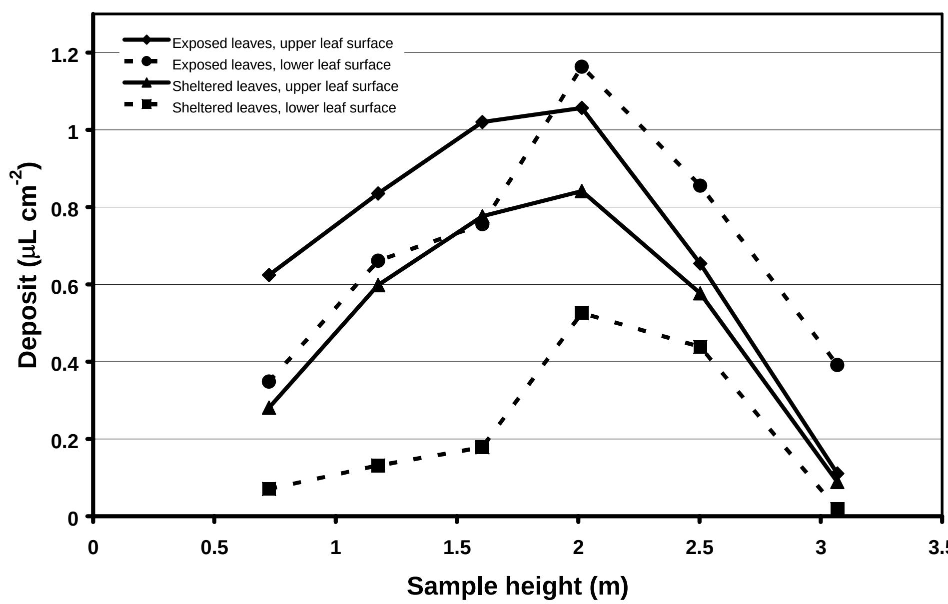


Figure 6. Liquid volumes deposited in the outer canopy of citrus trees sprayed with a single pair of horizontally converging spray heads.

4. CONCLUSIONS

- In our opinion pesticide rate per hectare is technically flawed because changing flow rate with row spacing alters the pesticide dose on the canopy. In addition, label rates per hectare are normally set too low for large or dense canopies, causing underdosing, and too high for small or sparse canopies, causing problems with excessive pesticide residues. These are the reasons why the pesticide label format for Australia for orchard crops has been changed.

- Using the point of first run-off, based on spray volume expressed in litres per 100 metres per metre of canopy height, is a simpler, more practical and accurate way to set the pesticide dose for orchard crops than dosing based on an amount of chemical per hectare. However, this requires pesticide labels, like that already adopted in Australia, based on a concentration of chemical applied to the point of first run-off, and the use of concentration factors for concentrate spraying that increase in the same proportion as the decrease in spray volume below the point of first run-off. It also requires pesticide amount per hectare to be removed from pesticide labels.

- The point of first run-off for dense citrus canopies using a direct blast multi-fan sprayer is probably 50 to 60 L per 100 metres per metre of canopy height (5000 to 6000 litres per sprayed hectare of vertical canopy wall).

- With point of first run-off used to set pesticide dose, spraying efficiency can be simply expressed as the spray volume in litres per 100 metres per metre of canopy height required to produce first run-off. The smaller the value, the more efficient the spray application. This is simpler and easier to understand than using normalised dose per hectare, and unlike normalised dose, is directly related to impacted dose per cm^2 of foliage.

- The importance of accurately determining the point of first run-off when applying concentrate sprays was demonstrated. If the point of first run-off is set too high, overdosing and excessive pesticide residues in produce can be the result. If it is set too low, the foliage is under dosed.

- The visual droplet rating chart technique to evaluate the deposition of fluorescent pigment was shown to be a very valuable, simple, low cost and practical field technique for evaluating spray coverage and impacted dose. It can be used to more accurately determine the "point of first run off" for the whole tree and to fine tune spray calibrations for specific crops and orchard situations, and also for sprayer type.

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