Effects of Travel Speed, Application Volume, and Nozzle Arrangement on Deposition and Distribution of Pesticides in Apple Trees

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ABSTRACT

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The effects of travel speed, application volume, and nozzle arrangement on the deposition and distribution of heavy metal compounds in apple trees were determined. The effect of sprayer travel speed was tested at 40, 54, 67, and 80 m/min; the effect of application volume was tested at 374, 617, 935, and 3,742 L/ha; and nozzle arrangement was tested as a ratio of percent total volume applied to the top one-third of the tree to the percent total volume applied to the bottom two-thirds of the tree (34:66, 50:50, 66:34, and 80:20). Each treatment application was replicated on the same six medium and small Golden Delicious apple trees. Under the conditions of this study, a travel speed of 54 m/min and a volume of water of 617 L/ha with a nozzle arrangement of 66:34% (top/bottom) on medium size trees and 50:50% (top/bottom) on small trees resulted in the highest mean deposit throughout the tree and the lowest variance of deposit.

Applicators make several operational decisions before applying pesticides to apple trees, including the model of orchard sprayer to employ, the volume of water to apply, and the travel speed of the sprayer. The applicator also uses judgment in directing two-thirds of the spray volume to the top one-third of the tree and the remaining one-third of the spray volume to the bottom two-thirds of the tree. This recommendation was first made by Brann (1) in 1965 after years of field observation and testing. Many other investigators also have examined these choices and have made similar recommendations for orchard applications (2,3,5,6,9).

Travis (12) found that pesticide deposits throughout apple trees were variable when sprayed under recommended "optimal" conditions and that disproportionate levels of deposit occurred in certain areas of the tree. He found that some variability could be eliminated by pruning the trees to a more open canopy density. Modification of some recommended parameters of operation may reduce variation in deposit and improve spray distribution in apple trees. In order to suggest any modification, deposition needs to be described throughout the tree and modifications compared with recommendations for sprayer operation.

The objectives of this study were to evaluate current recommendations for orchard pesticide application by determining the effects of travel speed, application volume, and nozzle arrangement on pesticide deposition and distribution in apple trees.

MATERIALS AND METHODS

The effect of travel speed on tracer deposition and distribution was tested at 40, 54, 67, and 80 m/min (1.5, 2.0, 2.5, and 3.0 mph, respectively); the effect of the volume of water applied was tested at 374, 617, 935, and 3,742 L/ha (40, 66, 100, and 400 gal/acre); and nozzle arrangement was tested as a ratio of percent total volume applied to the bottom two-thirds of the trees (34:66, 50:50, 66:34, and 80:20) (Table 1). The

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nozzles were about 0.5 m from the front of the tree. The heavy metal foliar micronutrients employed to determine the deposit were Sequestrene Cu (12%), Sequestrene 330 Fe (10%), Sequestrene Manganese (13%), and Sequestrene Zinc (14.2%) (Ciba-Geigy Corp., Greensboro, NC). These materials can be used as a measure of deposit achieved with pesticides (13). Deposits are reported in terms of an initial concentration of micronutrient in the sprayer tank of 1,920 μg/ml. The metal compounds were applied with an FMC John Bean (Model E200 TR) speed sprayer. Standard application recommendations (1), included in all tests for comparison, were a water volume of 617 L/ha applied at 54 m/min with a nozzle arrangement ratio of 66:34. Nozzles were redirected between treatments on small and medium trees to compensate for differences in tree height. Manifold pressure was 1,378.9 kPa. The specific nozzle sizes and arrangements are listed in a footnote at the bottom of Table 1. Applications were made when the temperature was 20–26 C, the relative humidity was greater than 70%, and there was no apparent air movement.

Each treatment was applied to three medium (about 3.6 [depth] × 4.1 [height] × 4.1 [width] m) and three small (about 3.1 [depth] × 3.1 [height] × 3.1 [width] m) Golden Delicious apple trees. All fruit were removed from the trees to maintain a uniform tree shape throughout the test period. Tests were conducted in midsummer, when the canopy was fully developed and most terminal buds had set. Cartesian coordinate frames were constructed over the trees. Nylon cord was drawn from the frame throughout each tree to mark the center point of each 244-cm^3 (1 ft^3) sample volume in the tree. The center point of each sample area was labeled with the three dimensional coordinates of the sample volume in the tree. Test trees were divided into three units: depth (divisions perpendicular to sprayer), height (height in the tree), and width (divisions parallel to the sprayer) (Fig. 1). After metal deposits had sufficient time for drying, the three closest leaves to the center point (within the sample volume) were collected and placed in small paper bags. Bags were identified as to the three dimensional coordinates of the sample volume, and the leaf samples were taken into the laboratory and the deposits analyzed by foliar mineral analysis as previously described (12). Leaf samples were collected within 24 hr of tracer deposition. Data were analyzed by Duncan's multiple range test and the variance expressed as $\log_{10}$ of the variance (LV) of deposit. The log transformation was applied because the mean of the deposits and variance of deposits were positively correlated. After the $\log_{10}$ transformation, the variance was independent of the mean.

RESULTS AND DISCUSSION

Interpretation of results. The deposition throughout the tree was measured within each 244 cm^3 of the tree. However, the deposit for each depth into the tree was averaged over all heights and widths; for each height, deposits for all depths and widths were averaged, and for each width, deposits for all depths and heights were averaged.

Effect of travel speed on deposition and distribution. Applications made at 40 and 54 m/min resulted in greater mean deposits than those made at 67 and 80 m/min (Table 2). The greatest variability in deposit occurred from applications made at 80 m/min. Deposits from applications made at 40 and 54 m/min

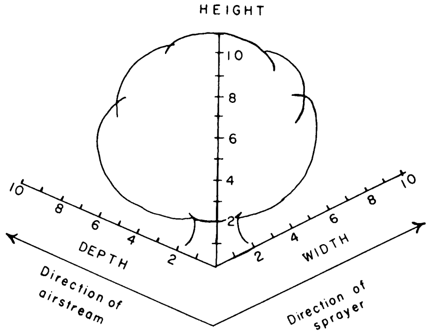

Fig. 1. Diagrammatic illustration of the three dimension coordinates used in describing deposit location (units in 30.5-cm [1-ft] increments).

Table 1. Travel speeds, water volumes applied per hectare, and nozzle arrangements used to trace deposition and distribution of spray applications on Golden Delicious apple trees

Application treatment[a]	Travel speed (m/min)	Water volume applied (L/ha)	Nozzle arrangement[b]
Travel speed	40	617[c]	66:34
	54	617[c]	66:34
	67	617[c]	66:34
	80	617[c]	66:34
Water volume	54	374[d]	66:34
	54	617[c]	66:34
	54	935[e]	66:34
	54	3,741[f]	66:34
Nozzle arrangement	54	617[c]	34:66
	54	617[c]	50:50
	54	617[c]	66:34
	54	617[c]	80:20

[a] Micronutrients were applied with an FMC John Bean model E200 TR speed sprayer.

[b] Given as the ratio of percentage of total spray volume directed to the top one-third of the tree to the percentage of spray volume directed to the bottom two-thirds of the tree.

[c] Using seven nozzles per side, top to bottom: D-5, D-4, D-4, D-4, D-3, D-3, and D-3 (all two-hole whirl plates).

[d] Using seven nozzles per side, top to bottom: D-2.5, D-2.5, D-2.5, and D-2.5 (two-hole whirl plates), D-3, D-3, and D-3 (one-hole whirl plates.)

[e] Using seven nozzles per side, top to bottom: D-7, D-6, D-6, D-5, D-4, D-4, and D-4 (all two-hole whirl plates).

[f] Using seven nozzles per side, top to bottom: D-8 (no whirl plate), D-8, D-8, D-7, D-6, D-6, and D-6 (three-hole whirl plates).

Table 2. Effects of travel speed, water volume applied per hectare, and nozzle arrangement on deposition of micronutrients in medium and small apple trees

	Travel speed (m/min)								
	40		54		67		80		
Tree size	Mean[a]	LV[b]	Mean	LV	Mean	LV	Mean	LV	No. samples each treatment
Medium	14.3	0.059	12.5	0.071	8.1	0.046	7.7	0.151	773
Small	17.0	0.079	15.6	0.082	7.8	0.072	8.0	0.223	386
	Water volume applied (L/ha)								
	374		617		935		3,742		
Medium	9.4	0.051	11.2	0.041	10.2	0.174	8.9	0.075	713
Small	8.1	0.090	13.2	0.500	13.2	0.098	7.7	0.043	402
	Nozzle arrangement[c]								
	34:66		50:50		66:34		80:20		
Medium	14.6	0.056	14.9	0.073	14.4	0.055	15.0	0.070	751
Small	15.5	0.033	17.1	0.064	15.3	0.052	16.1	0.040	411

[a] Expressed in μg/cm^2 of leaf tissue.

[b] LV is expressed as the variance of the $\log_{10}$ of μg deposit/cm^2 of leaf surface.

[c] Given in the ratio of total spray volume directed to the top one-third of the tree to the percentage of spray volume directed to the bottom two-thirds of the tree.

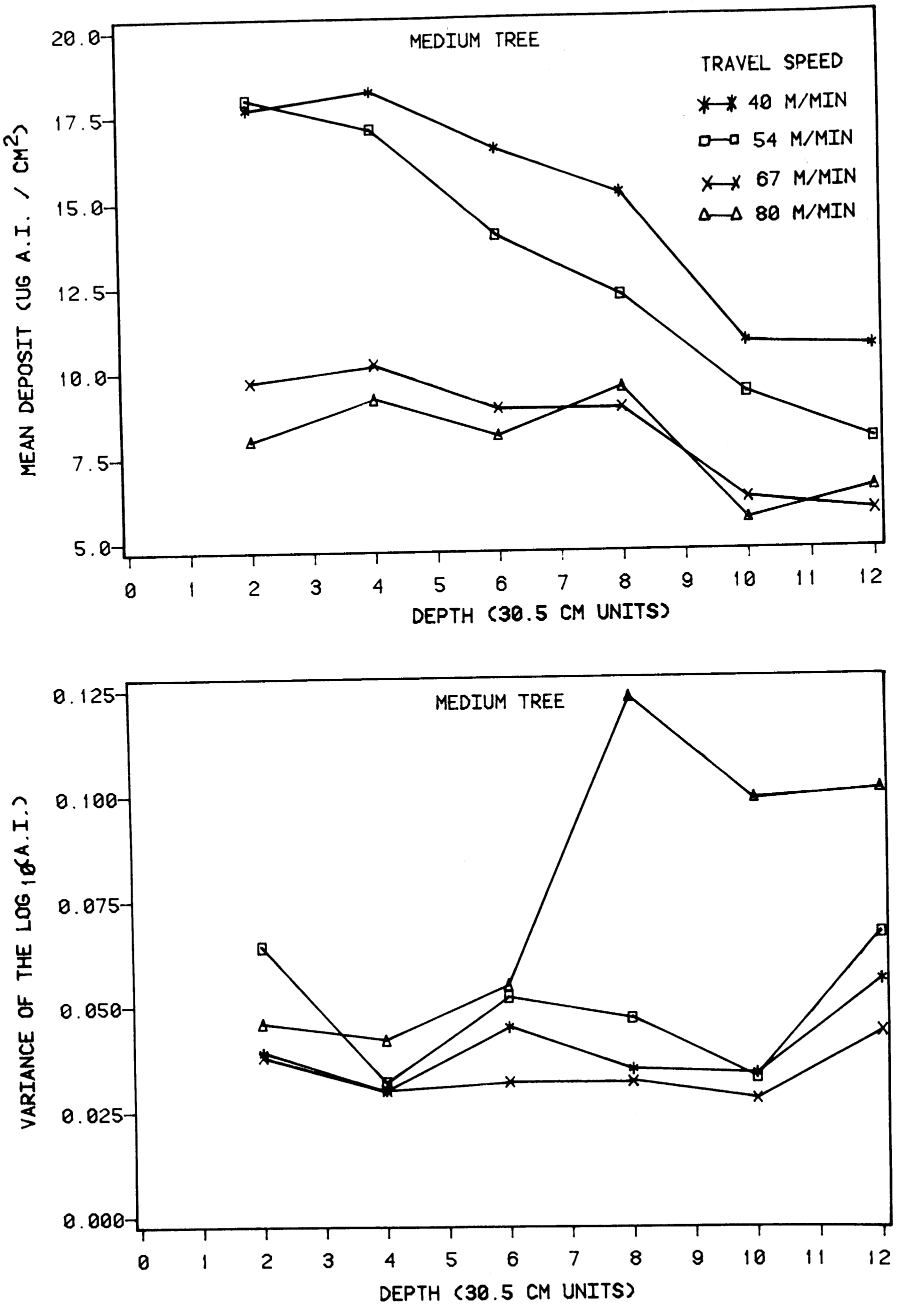

Fig. 2. Effect of travel speed on mean deposits and $\log_{10}$ of the variance of deposit at depths in medium trees.

were greater at each sampled depth into the trees than deposits at higher travel speeds (Figs. 2 and 3). The deposits from the 40- and 54-m/min applications declined more rapidly with increased distance from the sprayer than the faster travel speeds; the deposit levels in the front of the tree were initially higher in these treatments. Even on the side of the tree opposite from the sprayer, however, deposits were still higher for the slowest travel speeds. Pesticide deposit, besides being sensitive to tree size and travel speed, is also dependent on the distance of the target from the sprayer (10). Here, as expected, the greatest difference in deposit between travel speeds occurred in the fronts of the trees, with less difference in the backs of the trees because of the neutralizing effect of increased distance from the sprayer. The LVs of the four application travel speeds were similar in the fronts of both medium and small trees (Figs. 2 and 3). After depth 6, the variability increased only for the 80-m/min travel speed on medium trees and for the two faster speeds on small trees. Thus, the 67- and 80-m/min travel speeds did not result in lower deposits throughout the tree but did result in more variability in deposit, especially beyond the trunk. This variability might be expected because of the combined effects of travel speed on the rate of airstream velocity loss over distance and the interference of the tree canopy with spray penetration and droplet interception. Mean deposits at various heights in medium and small trees also were greater from the 40- and 54-m/min applications than from the 67- and 80-m/min applications (Fig. 4).

In this study, there appeared to be a natural separation of deposit levels between the two slower travel speeds and the two faster travel speeds. This difference in deposits was greater than the difference in travel speed. Perhaps, a critical travel speed was reached between 54 and 67 m/min, where a negative interaction occurred between travel speed and the other factors of application, such as

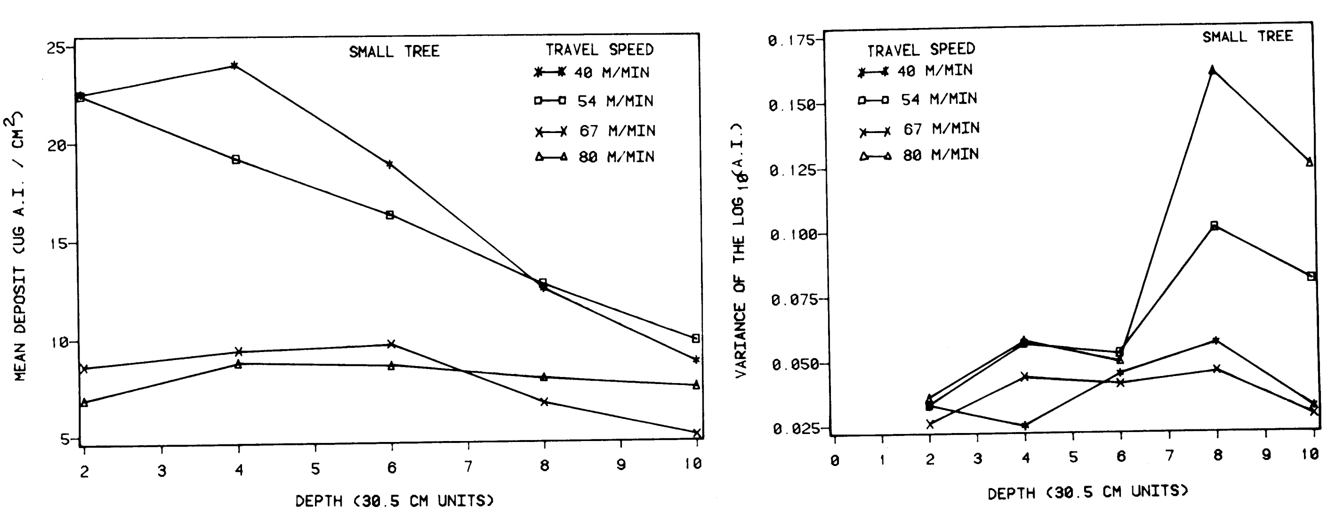

Fig. 3. Effects of travel speed on mean deposits and $\log_{10}$ of the variance of deposit at depths in small trees.

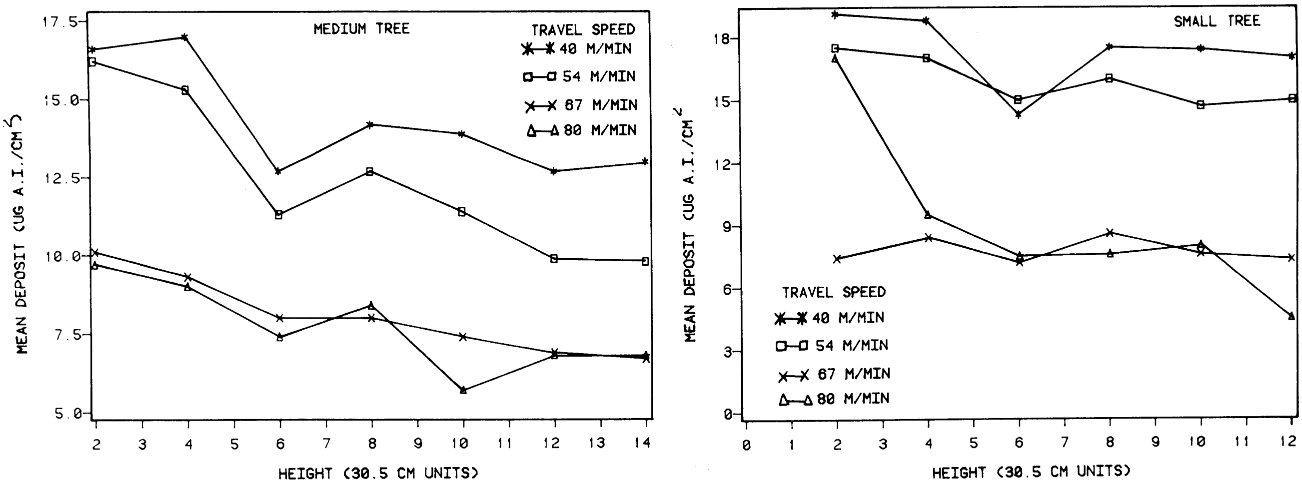

Fig. 4. Effects of travel speed on mean deposits and $\log_{10}$ of the variance of deposit at depths in medium and small trees.

air displacement in the tree, droplet impingement, droplet size, and interception by the canopy (1,3,4,8).

One would expect, as demonstrated here, that slower travel speeds result in more pesticide deposits per tree. Growers often operate sprayers at faster travel speeds intentionally to apply less pesticide to smaller trees or to trees early in the season with less foliage. Some growers travel faster to shorten the time required for application. Intuitively, this may seem like a good idea; however, although increasing travel speed does decrease deposits, there are several problems with this method. With increased travel speed, the final application rate per hectare is unknown unless it is calculated after the application. The relationship is not proportional in apple trees; twice the speed does not result in half the rate. In this study, rates were decreased by more than half with an increase in travel speed from only 54 to 67 m/min. The biggest problem with increasing travel speed to reduce rate is the increase in deposit variability throughout the tree, especially in the tops of trees, where pest control is often most critical and often lacking. Recalibrating sprayers for reduced fungicide application on small trees or trees of less foliage density is a better method than increasing travel speed to reduce the rate. Calibration offers both a known application rate and more uniformity in deposits throughout the tree, factors that are critical to disease management.

Effect of application volume on deposition and distribution. To apply a lower water volume per acre, nozzles must be selected that deliver less water per minute at a given travel speed. This is accomplished by using nozzles with small orifices that produce small droplets. Reichard et al (11) found wide ranges in droplet sizes produced by nozzles of different orifice sizes but relatively uniform droplet spectrums produced by

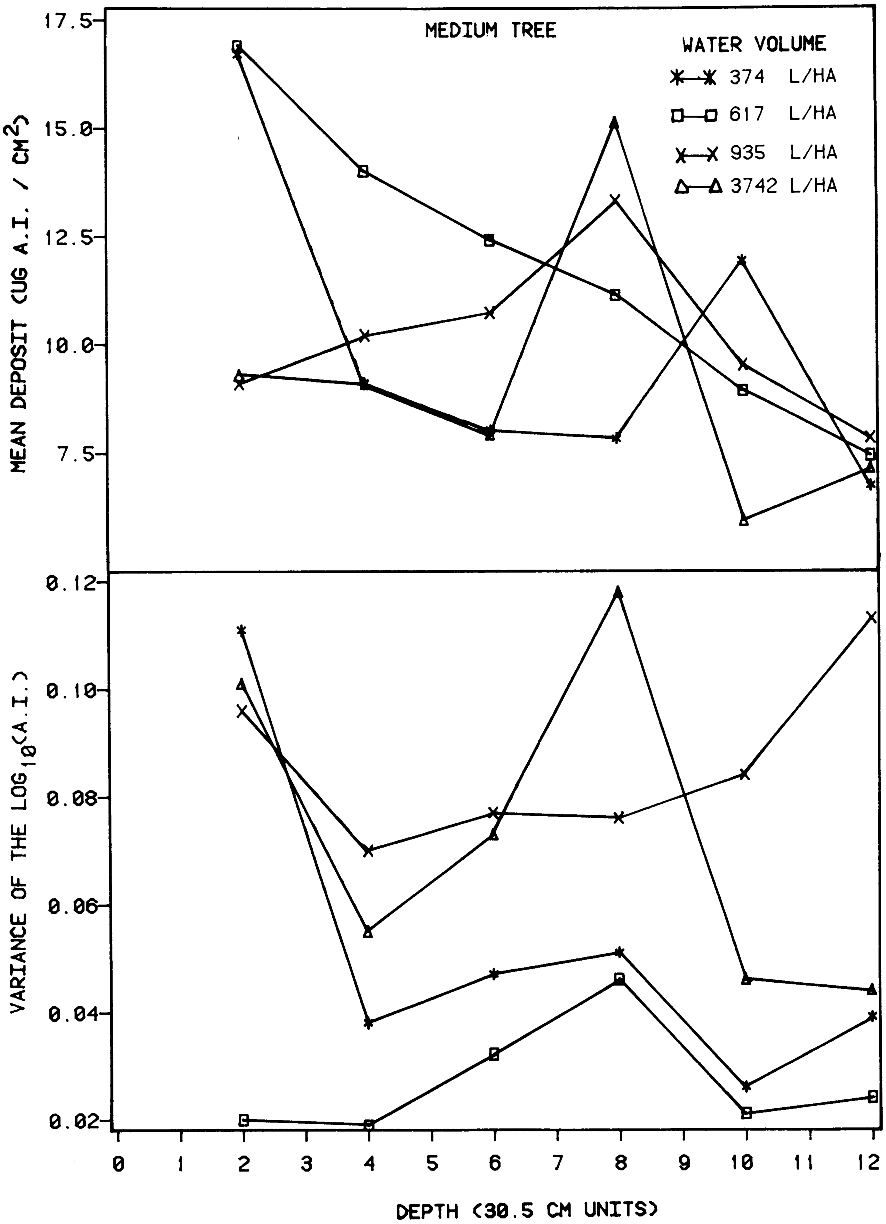

Fig. 5. Effect of application volume on mean deposit and $\log_{10}$ of the variance of deposit at depths in medium trees.

the same nozzle in repeated tests. They concluded that it was difficult to describe precisely the droplet spectrum produced from a specific nozzle, but in general, low-output nozzles produced more smaller droplets than high-output nozzles. The mixture of large to small droplets being used is critical to the effective application of the water volume. Courshee (3) observed that small drops, such as produced with low-volume applications, are readily deflected from their original sources. Cunningham et al (4) showed that, at low humidities, small droplets lose proportionately more water by evaporation than larger droplets because of their larger surface-to-volume ratio. As droplets become smaller from evaporation, their velocity becomes more critical for impingement. Cunningham et al (4) also showed that, although spray droplets leave the nozzle at relatively high velocities, droplet velocity is rapidly reduced over short distances. Because of greater mass, large droplets tend to be carried shorter distances in the airstream than small droplets but are less dependent on velocity for impingement (3). The most effective application volume and, therefore, droplet spectrum for the sprayer and tree sizes being evaluated will result in the highest mean deposits throughout the tree with the lowest variability in deposit.

In this study, mean deposits were lower from 374- and 3,742-L/ha applications than for the 617- and 935-L/ha applications (Table 2). This may appear to be inconsistent until one realizes that both volumes of water are at opposite ends of the spectrum of water volume range evaluated in this study. It is possible that the lower deposits at the 374-L/ha rate are due to the greater number of small droplets produced that did not impinge well at low velocities. Lower mean deposits at 3,742 L/ha may be due to the fact that runoff results in a thin layer of residue on the leaf compared with concentrated drop deposits achieved with other spray rates. It would appear as though the two middle application volumes tested (617 and 934 L/ha) were more suitably matched to tree size and sprayer output. That is, the interaction of the droplet spectrum, the fan air volume output, and the tree size and structure were more conducive to effective deposition and distribution. The greatest

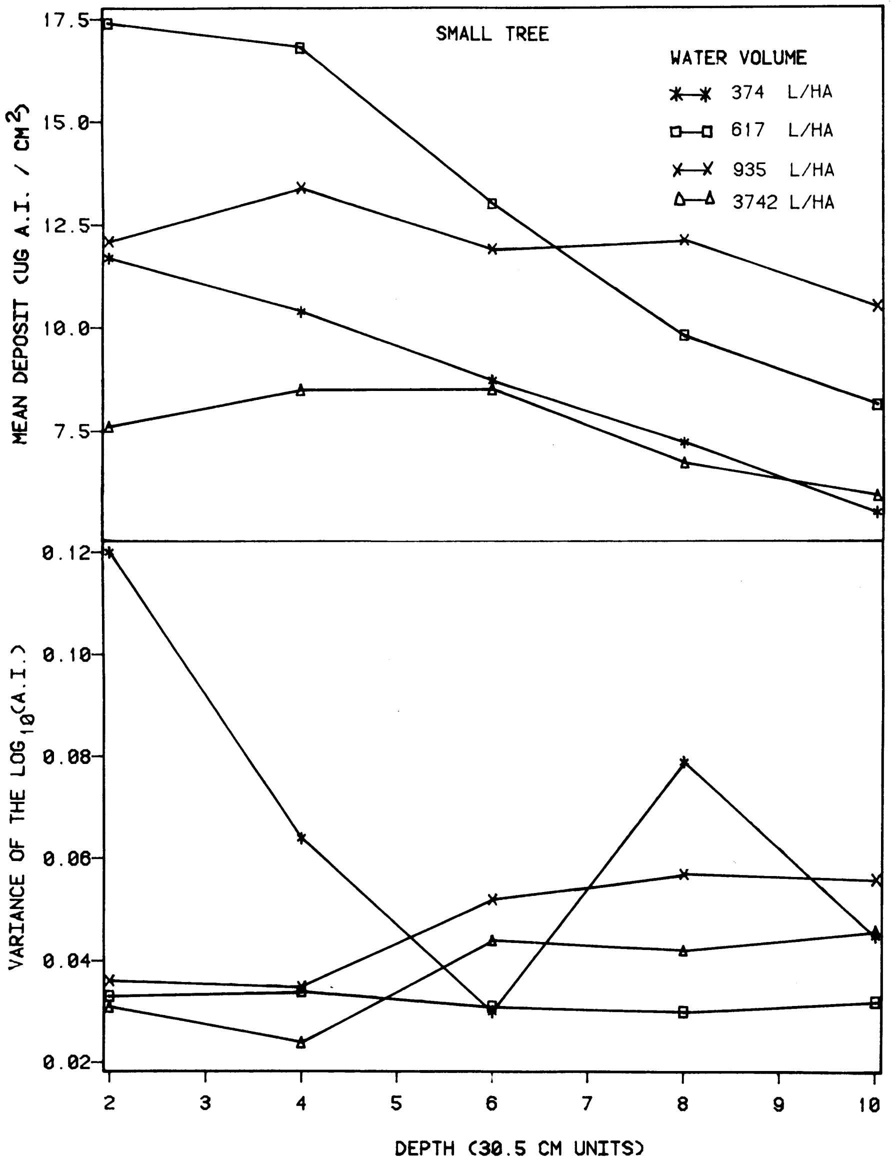

Fig. 6. Effect of application volume on mean deposit and $\log_{10}$ of the variance of deposit at depths in small trees.

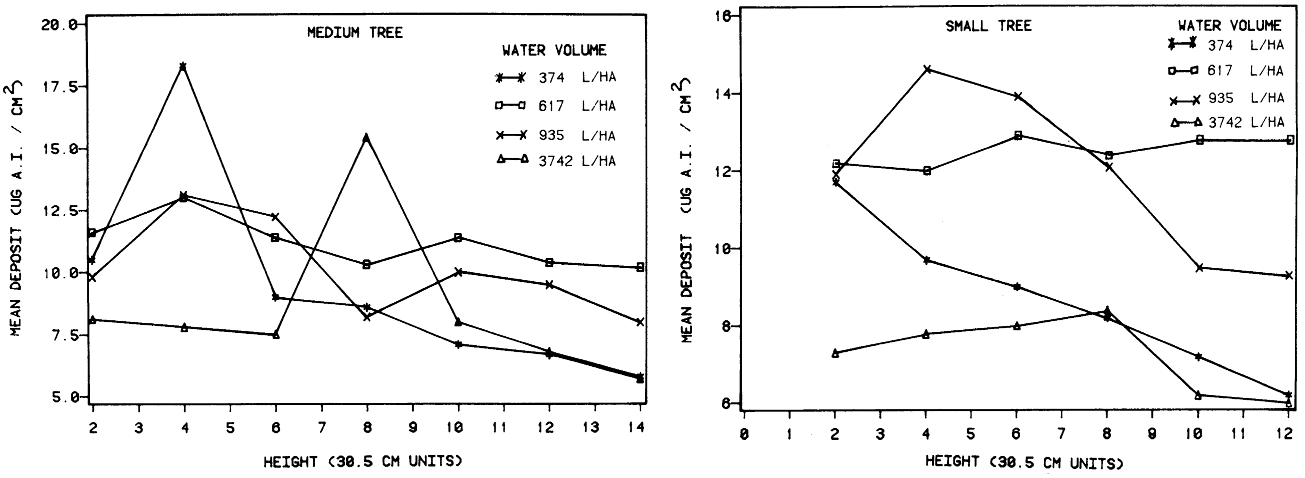

Fig. 7. Effect of application volume on mean deposit at heights of medium and small trees.

variability in deposit, however, was observed on trees receiving the 935-L/ha application (Table 2). This variability may be due to the fact that the 935-L/ha rate was intermediate between conventional low-volume rates where individual droplets impinge and little wetting occurs (617 L/ha) and high-volume dilute rates that flood the leaf surfaces (3,742 L/ha). Thus, at the 935-L/ha rate, some leaves close to the sprayer may have been thoroughly wetted to runoff while others at some distance were not. Because the 617-L/ha application resulted in a high deposit level and the lowest variability of deposit on both tree sizes, 617 L/ha was judged as the best application volume for the given sprayer and tree size. This conclusion is supported when individual deposits are examined at specific depths and heights of both size trees (Figs. 5–7). The 617-L/ha rate resulted in the highest mean deposit in the front half of both the medium and small size trees and provided consistent deposits with tree height.

Both the 935- and 3,742-L/ha applications resulted in a large increase in deposit about 0.6 m beyond the trunk. This may be the point at which the airstream can no longer support large droplets. A similar peak of heavy deposit occurred at depth 10 after the 374-L/ha application. No such peak of heavy deposit was evident with the 627-L/ha application. These peaks also did not occur on small trees after application of the same water volume, perhaps because of differences in the interaction between droplet spectrums and the smaller tree volume.

Effect of nozzle arrangement on deposition and distribution. Mean deposits and LVs did not differ between trees of the same size sprayed with different nozzle arrangements (Table 2). Because the water volume remains constant, only the distribution pattern within the tree should have been affected by changing the nozzle arrangement. Mean deposit differences did occur between nozzle arrangements at corresponding depths in medium trees (Fig. 8). Deposition from the 66:34 nozzle arrangement was greatest in the front of the tree to the trunk area but was less than the 34:66 and 80:20 arrangements on the back side of the tree. The 50:50 nozzle arrangement resulted in a disproportionate amount of the total deposit in the trunk area. On small trees (Fig. 8), mean deposits from all nozzle arrangements did not differ with depth in the front of the tree. Deposit on small trees was generally highest with the 50:50 arrangement (Fig. 8).

The 34:66 nozzle arrangement placed more spray deposit in the bottom of the medium tree than the other arrangements (Fig. 9). The 66:34 and 80:20 arrangements provided relatively uniform deposits with height on medium and small trees; however, variation in deposits was large with the 80:20 arrangement (Fig. 10). On small trees, the 50:50 nozzle arrangement generally maintained the greatest deposit with increased height in the tree (Fig. 9). The variance of the deposit in the lower portion of small trees (Fig. 10) was greatest with the 50:50 and 66:34 arrangements. Variation was generally less with the 34:66 arrangement.

When calibrating a sprayer, several factors are carefully set for accurate delivery of a water volume at predetermined water pressures and travel speed.

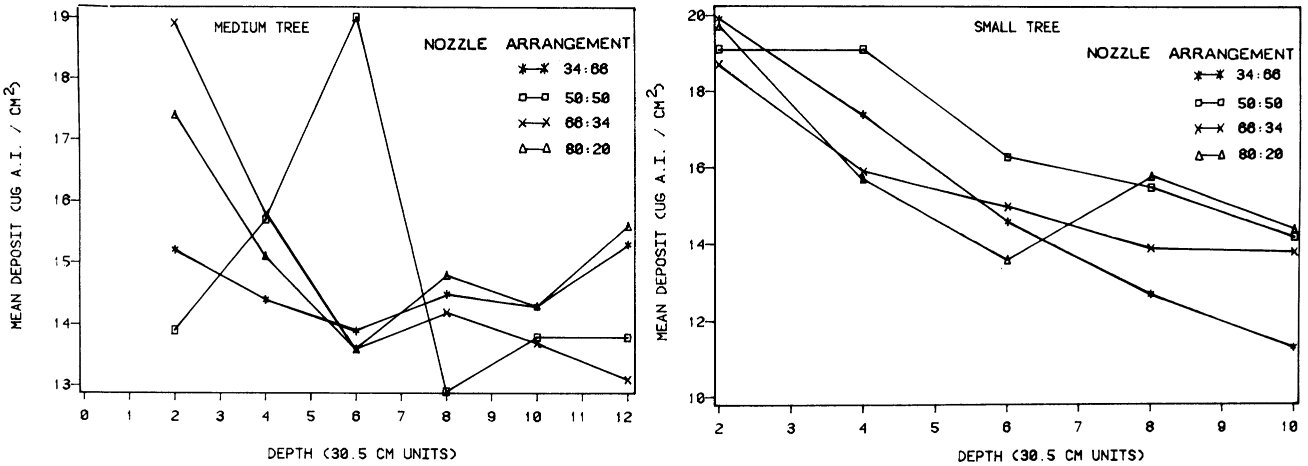

Fig. 8. Effect of nozzle arrangement on mean deposit at depths in medium and small trees.

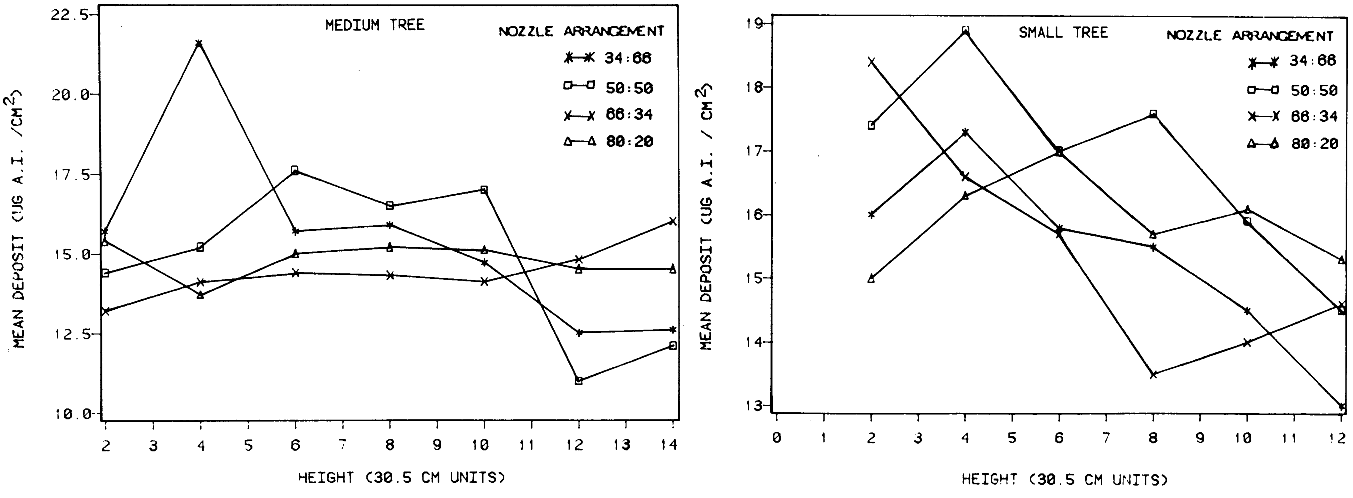

Fig. 9. Effect of nozzle arrangement on mean deposit at heights of medium and small trees.

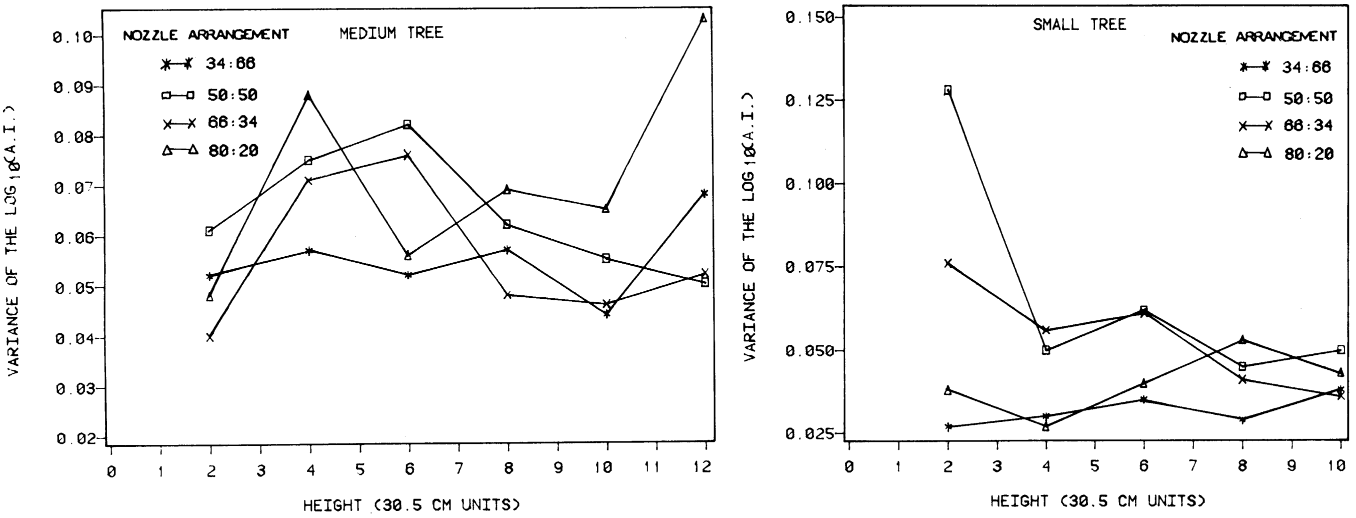

Fig. 10. Effect of nozzle arrangement on the $\log_{10}$ of the variance of deposit at heights of medium and small trees.

The nozzles are directed to deliver two-thirds of the spray volume to the top one-third of the tree and the remaining one-third spray volume to the bottom two-thirds of the tree. This recommendation was originally made by Brann in 1965 (1). Admittedly, nozzle arrangement is the most subjective portion of sprayer calibration. If the factors that affect deposit per tree remain the same, even with significant redirection of nozzles, no significant differences in total tree deposit occur; however, distribution patterns throughout the tree are significantly different. Deposition in the larger (medium) trees was generally more sensitive to the nozzle arrangement. This is probably due to the difficulty in propelling spray droplets the greater distances necessary to cover larger trees. Nozzle arrangement may be even more critical to deposition on larger trees than on smaller trees.

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