Evaluation of the Tree-Row-Volume Model for Full-Season Pesticide Application on Apples

T. B. SUTTON, Department of Plant Pathology, and C. R. UNRATH, Department of Horticultural Science, North Carolina State University, Raleigh 27695

ABSTRACT

Sutton, T. B., and Unrath, C. R. 1988. Evaluation of the tree-row-volume model for full-season pesticide application on apples. Plant Disease 72:629-632.

Chelated micronutrients were used to monitor spray deposits in apple trees resulting from dilute applications with an airblast sprayer at tight cluster, first cover, or fifth cover. Rates per hectare were adjusted before each application, according to a tree-row-volume model (TRV). Applications at phenophase tight cluster resulted in mean deposits 1.2–2.0 times greater than applications made at first or fifth cover. Increased deposit at tight cluster generally was consistent among trees pruned at three management levels (light, moderate, and heavy) and in two orchards with different size trees. Variation in deposit within trees was greater in larger trees in the Hillcrest Orchard than in smaller trees in the Justice orchard. The greater variation at Hillcrest was probably related to the difficulty of propelling water droplets throughout the canopy of large trees (up to 6.53 m tall and 8.69 m wide). Our results indicate that the TRV model is a suitable guide for early season as well as cover spray applications. The increased deposit obtained at tight cluster should not be viewed as justification for reducing pesticide rates per hectare in early season sprays.

The tree-row-volume model (TRV) is a method for determining the amount of pesticide required per hectare (11). The concept was originally developed for use on tree fruits (3,5), but is applicable for any crop plant in which canopy volume varies from year to year or increases during the growing season. The tree-row-volume model is based on the assumption that each row of trees within the orchard is a wall of foliage and the amount of pesticide needed is related to the volume of foliage within that wall. According to the tree-row-volume model, 1 L of dilute chemical suspension will wet 7.48 m^3 of foliage to runoff. Adjustments to the TRV rate per hectare are made depending on the material used and the desired response. For example, growth regulator applications for such responses as inhibition of vegetative growth and thinning spur Red Delicious are applied to runoff at 100% of the TRV dilute base (8,11). On the other hand, fungicides and insecticides are applied to the drip point at 70% of the TRV dilute base (1 L/10.24 m^3 of foliage) (8). This is the rate that has been historically used for fungicide and insecticide applications (7). The rate per hectare is then calculated from the labeled rate of the chemical/100 L and the adjusted volume of foliage per hectare.

Consistent deposits can be obtained on trees of varying size and pruning level by using the TRV model with density adjustments (9). Currently, TRV is recommended as a guide for pesticide application in several states (6,8,12). However, the TRV model has been evaluated only for applications made to a full canopy of foliage. It is not known if use of the TRV model as a guide for early season sprays will result in deposits comparable to cover spray applications. Early season sprays, when the canopy is not filled out, are extremely critical for the control of many orchard pests such as tarnished plant bug, apple scab, powdery mildew, cedar apple rust, and black rot. In addition, growth regulators such as 6-benzyladenine + giberellin A4A7 (Promalin, Abbott Laboratories, N. Chicago, IL) are applied at early petal-fall when canopy development is slight.

The objective of this research was to evaluate the TRV model as a guide for full-season pesticide application.

MATERIALS AND METHODS

Orchards. In 1985, the study was conducted in a 25-yr-old orchard at Hillcrest Orchards, Henderson County, NC (Hillcrest). In 1986, the study was conducted at Justice Orchards (Justice) in a 16-yr-old orchard in Henderson County, NC. Twelve trees of similar size and general limb structure were selected within a row for use in each orchard. At Hillcrest, trees were cv. Delicious; at Justice, trees were cv. Golden Delicious. Four trees each were randomly selected and three pruning levels were established: light or no pruning, moderate pruning, and heavy pruning. In lightly pruned trees, only dead and broken branches and basal water sprouts were removed. Upright growth was removed in moderately pruned trees to reduce shading, and branches were headed back to maintain the tree in its space. In heavily pruned trees, limbs were removed to open the tree and establish a balanced limb structure. Upright growth was removed and heading cuts were made as described for moderately pruned trees. Trees were pruned in March of each year before growth began. Heavily pruned trees were desprouted before the fifth cover spray application. The descriptions of the trees used in the study are presented in Tables 1 and 2.

Tree-row-volume and density adjustments. The tree-row-volume model was calculated as follows: TRV(m^3 foliage/ha) = (10,000 m^2/ha × tree height [m] × limb spread [m]/cross-row spacing [m]). To determine the quantity of water necessary for each application, TRV was first adjusted for foliar density on a scale ranging from 0.7 to 1.0 (8,9). A density adjustment of 0.7 refers to trees extremely open with light penetration through the tree canopy, while an adjustment of 1.0 refers to trees unpruned and extremely dense with no light penetration through the tree canopy. The final water volume per hectare was determined by multiplying TRV adjusted for canopy density by 1 L/7.48 m^3 (1 U.S. gal/1,000 ft^3). The fraction 1 L/7.48 m^3 was used because 1 L of water has been found sufficient to wet the foliage occupying 7.48 m^3 of canopy volume to the point of runoff (11). Tree-row-volume density adjustments and the volumes of water used in each application are listed in Tables 1 and 2.

Treatment application and deposit determination. Heavy metal chelated micronutrients were used to determine deposit levels (10). Those used were Sequestrene Zinc (Zn, 14.2%), Sequestrene Manganese (Mn, 12.0 %), Sequestrene Copper (Cu, 13.0%), and Sequestrene 330 Fe (Fe, 10.0%) (Ciba-Geigy Corp., Greensboro, NC). Solutions of 500 μg heavy metal/ml were applied in all tests. A different micronutrient was applied to trees in each pruning level. The micronutrient used was dependent on the micronutrient used previously and the grower pesticide use. A random sample

Paper No. 11268 of the Journal Series of the North Carolina Agricultural Research Service, Raleigh 27695-7601.

Use of trade names does not constitute endorsement by the North Carolina Agricultural Research Service of the products named nor criticism of similar ones not mentioned.

Accepted for publication 9 February 1988 (submitted for electronic processing).

of 50 leaves was taken from each tree before micronutrient application in order to determine background micronutrient levels.

Treatments at Hillcrest were applied with a Meyers model 2A36 speed sprayer (F. E. Meyers & Bros. Co., Ashland, OH) driven at 54.6 m/min (2 mph). Manifold pressure was 213.7 kPa. The first application at Justice was made with a Vanguard speed sprayer (Tifone, 44044 Cassona. [Ferrara], Italy) that was driven at 49.1 m/min (1.8 mph). The manifold pressure was 320.6 kPa. The second and third applications at Justice were made with a Swanson DA500 speed sprayer (Durand-Wayland, Inc., La Grange, GA). The manifold pressure was 160.2 kPa and the sprayer was driven at 49.1 m/min (1.8 mph). Various combinations of nozzle numbers and disk and core sizes were used to deliver the desired volume of water. Nozzle arrangement and direction were adjusted for each tree size to match the spray pattern with tree height and to deliver two-thirds of the spray volume to the top one-third of the tree and one-third of the spray volume to the bottom two-thirds of the tree. The sprayers were driven approximately 1.5 m from the edge of the canopy of each tree.

Trees at Hillcrest were partitioned into six regions for sample collection and those at Justice were partitioned into four regions. Trees partitioned into four regions were divided by a vertical plane in the center of the tree within the row and by a horizontal plane at the midpoint of the tree. Regions 1 and 2 were in the lower half of the tree and regions 3 and 4 were in the top half. Trees partitioned into six regions were divided by two vertical planes in the row into three sections of equal width (right, middle, left). Each vertical section was also divided into an upper and lower segment at the midpoint of the tree height. Regions 1, 2, and 3 were in the lower half of the tree and regions 4, 5, and 6 were in the upper half. Regions 2 and 5 were in the center.

Five three-leaf samples were picked at random from each region after the deposit had dried. Leaves that were picked were within 10 cm of one another and were picked by their petioles to minimize contact with the leaf surfaces. Each three-leaf sample was placed in a paper bag, labeled, and stored at 2 C until analyzed. Heavy metal deposit/cm^2 leaf tissue was determined as previously described (10).

Application dates. In 1985, applications were made on 11 April (tight cluster) and 15 July (fifth cover). In 1986, applications were made on 9 April (tight cluster), 14 May (first cover), and 23 July (fifth cover). All applications were made in the morning between 0900 and 1200 hours. Spraying was conducted only when the wind was less than 3 km/hr. All dew had dried before application.

Experimental design and data analysis. The experimental design was a split-split-plot with date of application being factor A, pruning level factor B, and region factor C. The analysis of variance was performed accordingly. Following testing in connection with the analysis of variance, LSDs were computed to compare two pruning levels within an application date and two application date main-effect means. Least significant differences were also computed to compare to region means within an application date.

RESULTS AND DISCUSSION

Applications made at tight cluster resulted in mean deposits 1.2–2.0 times greater than applications made during the cover spray period. These results were consistent between the tight cluster and fifth cover applications at Hillcrest in 1985 and between the tight cluster and first and fifth cover applications at Justice in 1986 (Tables 3 and 4). Deposit was significantly greater (P = 0.05) at tight cluster than in the cover sprays for all pruning levels, except for the lightly pruned trees at Hillcrest (Tables 3 and 4).

The use of different sprayers in the tight cluster vs. the first and fifth cover sprays at Justice could have influenced the magnitude of the difference in the deposit between tight cluster and first and fifth cover. However, the sprayers are very similar and the differences in deposit should be slight. Both sprayers produce a similar air volume (1,245.9 m^3/min of air for the Swanson vs. 1,202.5 m^3/min for the Vanguard) and velocity (207.6 km/hr for the Swanson vs. 170.5 km/hr for the Vanguard). Seven to nine nozzles were used to deliver the water volume to treatments with the Vanguard sprayer, whereas seven to eight were used

Table 1. Description of trees in the Hillcrest orchard used in tree-row-volume (TRV) studies in 1985

	Tree size[x]		Application date					
			11 April			15 July		
Pruning level[w]	Height (m)	Width (m)	Density adjustment[y]	TRV (m^3)	L/ha[z]	Density adjustment	TRV (m^3)	L/ha
Heavy	5.00	6.83	0.70	26,185	3,492	0.90	35,612	4,761
Moderate	5.43	7.14	0.75	31,778	4,249	0.95	42,187	5,640
Light	6.53	8.69	0.85	52,715	7,047	1.00	64,507	8,624

[w]See text for detailed description of pruning levels.
[x]Tree size at green tip.
[y]See references 8 and 9 for description of canopy density adjustments.
[z]Based on 1 L of dilute pesticide suspension required to wet 7.48 m^3 of foliage to the drip point.

Table 2. Description of trees in the Justice orchard and in tree-row-volume (TRV) studies in 1986

	Tree size[x]		Application date								
			9 April			14 May			23 July		
Pruning level[w]	Height (m)	Width (m)	Density adjustment[y]	TRV (m^3)	L/ha[z]	Density adjustment	TRV (m^3)	L/ha[z]	Density adjustment	TRV (m^3)	L/ha[z]
Heavy	4.51	4.18	0.71	17,553	2,347	0.75	18,543	2,479	0.80	19,732	2,638
Moderate	5.40	5.06	0.83	29,742	3,976	0.88	31,483	4,209	0.93	33,233	4,443
Light	5.95	5.49	0.93	39,841	5,326	0.95	40,721	5,444	0.95	40,721	5,444

[w]See text for detailed description of pruning levels.
[x]Tree size at green tip.
[y]See references 8 and 9 for description of canopy density adjustments.
[z]Based on 1 L of dilute pesticide suspension required to wet 7.48 m^3 of foliage to the drip point.

with the Swanson sprayer. Visual observation during sprayer operation also indicated a similar spray pattern.

The increased mean deposit obtained at the tight cluster application is probably a result of greater penetration of the droplet-laden airstream into the upper canopy. Furthermore, since the airstream would not be impeded by foliage, droplet velocity would be greater resulting in more efficient deposition (1).

Deposit was more consistent at Justice than Hillcrest. At Justice, deposit was greater in region 4 than the other three regions at tight cluster. However, at first and fifth cover, deposit generally was greater in regions 1 and 2 than in regions 3 and 4 (Table 5). Deposits were higher at Hillcrest in the lower half of the tree after both tight cluster and fifth cover applications (Table 6). Furthermore, deposits in regions within the lower and upper halves of the trees were significantly different from one another. At fifth cover, deposits in the center regions were less than the two outer ones. The coefficients of variation at Justice were generally less for all treatment applications than for comparable applications at Hillcrest (Tables 3 and 4). Coefficients of variation among pruning levels were least variable for the first cover application at Justice.

Table 3. Mean deposits per cm^2 of leaf tissue and coefficients of variation for application of micronutrients made to trees pruned at three levels at Hillcrest on 11 April (tight cluster) and 15 July (fifth cover) in 1985

	Application date			
	11 April		15 July	
Pruning level[x]	Deposit[y]	Coefficient of variation	Deposit	Coefficient of variation
Heavy	3.09	26.1	1.57	51.8
Moderate	3.33	27.6	1.78	49.5
Light	3.29	52.0	2.74	68.5
$LSD_{05} = 0.68$[z]				

[x] See text for detailed description of pruning levels.
[y] Deposit in μg micronutrient per cm^2 of leaf tissue.
[z] LSD_{05} for mean deposit between application date and among pruning levels.

Table 4. Mean deposits per cm^2 of leaf tissue and coefficients of variation for application of micronutrients made to trees pruned at three levels at Justice on 9 April (tight cluster), 14 May (first cover), and 23 July (fifth cover) in 1986

	Application date					
	9 April		14 May		23 July	
Pruning level[x]	Deposit[y]	Coefficient of variation	Deposit	Coefficient of variation	Deposit	Coefficient of variation
Moderate	2.98	28.3	2.28	35.2	2.19	28.3
Light	4.27	35.3	2.50	37.6	2.50	35.3
Heavy	3.38	48.5	2.28	36.0	2.13	48.4
$LSD_{05} = 0.67$[z]						

[x] See text for detailed description of pruning levels.
[y] Deposit in μg micronutrient per cm^2 of leaf tissue.
[z] LSD_{05} for mean deposit between application date and among pruning levels.

Table 5. Mean deposit per cm^2 of leaf tissue by region for application of micronutrients made to trees pruned at three levels at the Justice orchard on 9 April (tight cluster), 14 May (first cover), and 23 July (fifth cover) in 1986

	Application date		
Region[x]	9 April	14 May	23 July
1	3.22[y]	2.56	2.71
2	3.36	2.66	2.76
3	3.56	2.18	1.72
4	4.00	2.00	1.83
$LSD_{05} = 0.42$[z]			

[x] See text for detailed description of regions within trees.
[y] Deposit in $\mu g/cm^2$ of leaf tissue.
[z] LSD_{05} for regions within sampling dates.

Table 6. Mean deposit per cm^2 of leaf tissue by region for application of micronutrients made to trees pruned at three levels at Hillcrest on 11 April (tight cluster) and 15 July (fifth cover) in 1985

	Application date	
Region[x]	11 April	15 July
1	3.91[y]	2.92
2	4.08	2.03
3	3.85	2.55
4	2.46	1.38
5	2.30	0.91
6	2.81	1.72
$LSD_{05} = 0.31$[z]		

[x] See text for detailed description of regions within trees.
[y] Deposit in $\mu g/cm^2$ of leaf tissue.
[z] LSD_{05} for regions within sampling dates.

Poorer distribution and greater variation in micronutrient deposit in the trees at Hillcrest than Justice is probably related to the difficulty of propelling the micronutrients to the top and the inside of large trees. Trees at Hillcrest ranged from 5.0 to 6.53 m tall and 6.83 to 8.69 m wide. Although the sprayer we used had a relatively large fan capacity (2,548.5 m^3/min), we observed reduced air movement in the tops and centers of the trees at Hillcrest. This was particularly true of the lightly pruned trees in which little spray material was blown through the canopy at fifth cover. Fisher (4) also found that the top branches of trees were often undersprayed. He suggested that in tall trees a reduction in air velocity resulted in lower impaction of the spray drops, and that the skirt areas of the trees are too dense to allow penetration of the droplet-laden airstream. It is likely that both factors were important in this study, although reduced air velocity may have been more of a problem at Hillcrest because of the large tree size.

Through the use of TRV with density adjustments, similar deposits were maintained among the three pruning levels, although the volume of water per hectare varied over twofold from lightly pruned to heavily pruned trees (Tables 1 and 2). At Hillcrest, there was no difference ($P = 0.05$) in deposits among the pruning levels at tight cluster. At fifth cover, deposit was higher on lightly pruned trees than moderate or heavily pruned ones (Table 3). At Justice, there was greater deposit ($P = 0.05$) in lightly pruned trees at tight cluster and no difference in deposit levels at any of the pruning treatments at first or fifth cover (Table 4). However, there was a trend to slightly higher deposits on lightly pruned trees in the cover sprays.

Spray drift to adjacent rows could result in greater deposit than was found before bloom when canopy development is slight and during full leaf in orchards with small, well-pruned trees. Byass (2) found that in small bush trees (3–3.5 m tall) drift contributed up to 40% of the final deposit. However, in larger trees (6–6.5 m tall) drift contributed significantly less to the total deposit. Sutton and Unrath (9) found in small, well-pruned trees (approximately 3 m tall) that drift resulted in a 34% increase in deposit. However, in larger, moderately pruned trees (approximately 4.0–4.9 m tall) there was no significant increase in deposit from drift. Thus, before petal-fall, when canopy development is slight, drift would probably result in an increase in deposit over the levels reported. However, as the canopy developed, drift would probably have not been a significant factor. Under grower situations when sprays are often applied in windy conditions, drift is likely to be more important. The relationship between pruning level and drift under windy conditions is not known.

Our results indicate that the TRV model is a suitable guide for applying pesticides in early season as well as cover spray applications. The increased early season deposit that we obtained should not be interpreted as justification for reducing the rate of pesticide per hectare in the early season sprays. A larger deposit may be desirable in early season, compared with the deposit in the cover sprays in terms of disease, insect control, or growth regulator response. In the case of fungicides or insecticides that act as protectants, more deposit would be available in early season for redistribution onto rapidly growing tissues. In the case of systemic fungicides, more material would be available for uptake. This could be particularly critical for fungicides such as the demethlyation inhibitors that are used as an eradicant in the control of apple scab (*Venturia inaequalis* (Cooke) Wint.).

ACKNOWLEDGMENTS

Appreciation is extended to L. R. Pope, J. D. Obermiller, and E. M. Brown for the technical assistance, and to L. A. Nelson for help with the statistical analysis. We thank Ciba-Geigy Corp. for providing the Sequestrene micronutrients. We also thank J. H. Stepp, Jr. and Kenneth Justice for use of their orchards and sprayers.

LITERATURE CITED

1. Brann, J. L., Jr. 1964. Factors affecting use of airblast sprayers. Trans. Am. Soc. Agric. Eng. 7:200-203.
2. Byass, J. B., and Charlton, G. K. 1964. Spray drift in apple orchards. J. Agric. Eng. Res. 9:48-59.
3. Byers, R. E., Hickey, K. D., and Hill, C. H. 1971. Base gallonage per acre. VA Fruit 60:19-23.
4. Fisher, R. V. 1970. Problems associated with spraying large apple trees in Ontario. Proc. Entomol. Soc. Ont. 101:35-40.
5. Herrera-Aguirre, E., and Unrath, C. R. 1980. Chemical thinning response of delicious apples to volume of applied water. HortScience 15:43-44.
6. Horsburg, R. L., Pfeiffer, D. G., Fell, R. D., Hogmire, H. W., Jr., Barden, J. A., Byers, R. E., Kushad, M. M., Marini, R. P., Rollins, H. A., Baugher, T. A., Ingle, L. M., Young, R. S., Drake, C. R., Yoder, K. S., Weaver, M. J., Barrat, J. G., Kotcon, J. B., Derr, J. F., and Foy, C. L. 1987. 1987–1988 Spray Bull. Comm. Tree Fruit Grow. VA and WV Coop. Ext. Serv. Publ. 456-419. 157 pp.
7. Lewis, F. H., and Hickey, K. D. 1972. Fungicide usage on deciduous fruit trees. Annu. Rev. Phytopathol. 10:399-428.
8. Rock, G. C., Walgenbach, J. F., Skroch, W. A., Unrath, R. C., Williams, K. M., Richie, D. F., Sutton, T. B., Shelton, J. E., and San Julian, G. J. 1987. Agricultural chemicals for North Carolina apples. NC Agric. Ext. Serv. Publ. AG-37. 50 pp.
9. Sutton, T. B., and Unrath, C. R. 1984. Evaluation of the tree-row-volume concept with density adjustments in relation to spray deposits in apple orchards. Plant Dis. 68:480-484.
10. Travis, J. W., Sutton, T. B., and Skroch, W. A. 1985. A technique for determining the deposition of heavy metals in pesticides. Phytopathology 75:783-785.
11. Unrath, C. R., Sutton, T. B., Obermiller, J. D., and Williams, K. M. 1986. A tree-row-volume model for determining proper spray rates in apple orchards. NC Apple Grow. Assoc. Publ. 001. 8 pp.
12. Wilcox, W. F., Riedl, H., and Stiles, W. C. 1986. Cornell recommendations for commercial tree fruit production. Cornell Univ. Agric. Exp. Stn. and NY State Agric. Exp. Stn., Geneva, NY. 75 pp.