Results of this experiment are in general agreement with the results of our previous experiment (7) that were obtained under the same grove conditions with different sample locations. However, different grove and spraying conditions may yield different results.

On the basis of these results, it was concluded that as spray volume decreases, mean deposit and variability of deposition increases. However, the trend is not consistent throughout the canopy and could be affected by sample location.

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SPRAY VOLUME AND ACARICIDE RATE EFFECTS ON THE CONTROL OF THE CITRUS RUST MITE

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Abstract. **In two independent field experiments on mature 15 to 18 ft high 'Valencia' orange trees, residual control of citrus rust mite, *Phyllocoptruta oleivora* (Ashmead) was evaluated at a constant and variable rate of selected acaricides at different spray volumes ranging from 25 to 1000 gal/acre using an airblast sprayer. The preceding paper presents data on foliar spray coverage using copper tracer methodology.**

In all experiments, no significant differences in initial mortality or residual control of citrus rust mite on fruit was found between spray volumes regardless of rate of application or acaricide. Residual control was affected by the kind and rate of acaricide used in the test. No significant interaction between spray volume and acaricide rate was detected indicating that acaricide rate affected the control of citrus rust mite regardless of the change in spray volume.

Residual control of the citrus rust mite on leaves at different canopy locations at different spray volumes was difficult to assess because of high variability in mite population density between samples. Residual mite control was significantly better on leaves in the upper compared to the lower tree canopy. Interestingly, mean cumulative mite days on leaves treated with copper (tracer) were significantly lower than on untreated leaves.

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The citrus rust mite, *Phyllocoptruta oleivora* (Ashmead) is ubiquitous on citrus in most humid citrus-growing regions of the world where it infests twigs, leaves, and fruit of all citrus varieties (15, 25). In Florida, the citrus rust mite (CRM) is primarily a pest of fruit destined for the fresh market though occasionally under ideal physical and cultural conditions favoring the mite (15, 17), its injury from cellular feeding can affect fruit growth (2), fruit drop (1), internal fruit quality (16) and external fruit quality (14, 15).

Since the CRM inhabits the new fruit and foliage each year in March and April (12) and reaches injurious population densities anytime from early June to November (3, 15, 17), it is common for growers to apply 3 to 4 acaricidal sprays during the year. This need to spray frequently for CRM is influenced by its biological attributes; that is, its inherent ability to increase to injurious densities on fruit quickly (14) and its small size which makes it extremely difficult to monitor in the field in order to time acaricide treatment accurately.

Since the CRM prefers to inhabit the fruit and foliage of the outer canopy of the tree (12), both common sense and the published data suggest that thorough spray coverage of the total tree canopy is not crucial, and it should be amenable to control via concentrate (low volume) spraying.

From the pioneer works at the Citrus Experiment Stations at Lake Alfred, FL and Riverside, CA, studies with multi-head sprayers, air-blast sprayers, aircraft and low volume sprayers have demonstrated successful control of citrus rust mite (4, 5, 6, 7, 9, 21) and citrus red mite (10). Recent studies suggest that low volume application also has potential for pests such as greasy spot disease that inhabit the underside of the leaf (24). Recently, Salyani and McCoy (19) found that small spray droplets gave uniform coverage on fruit, less coalescence of droplets for runoff, and a higher mortality of citrus rust mite.

Of the various components that operate in spray technology, spray volume reduction is one key factor that will decrease application costs (23). Environmentally speaking, a reduction in runoff alone will minimize air, soil, and water contamination. Naturally, the use of less water per acre will produce savings in labor, fuel, and machinery cost (23). Therefore, it is reasonable to assume that grower interest in concentrate (low volume) spraying will increase in the future.

Field studies have been conducted during the last 4 yr to elucidate the effect of reduced spray volume on the control of citrus rust mite with contemporary acaricides and determine factors responsible for success or failure of an application (20). Previous research has focused on quantification of spray deposition on the tree canopy in relation to mite control. Field studies conducted in 1985 and 1986 showed that spray volume had no significant effect on mean tracer deposition and citrus rust mite control while higher spray volumes showed more uniform coverage than the lower volumes (20) (Table 1). Both this and the previous paper (18) present additional research data on 1) deposition characteristics within the tree canopy at different spray volumes and 2) the effect of spray volume and acaricide rate on the residual control of the citrus rust mite.

Materials and Methods

Field Test—1987

Experimental design. The experiment was conducted near Lake Wales, FL at Alcoma Fruit Company on mature 15 to 18-ft high orange (*Citrus sinensis* var. *valencia* (L.) Osbeck) trees with excellent leaf canopy density. Eight treatment combinations (2 acaricides, 4 spray volumes) plus an unsprayed control were arranged in a randomized block design and replicated 4 times. The trees were spaced 20 x 30 ft with 72 trees/acre. Trees were of uniform size and shape and were not recently hedged. Each plot consisted of 6 rows of 6 trees with all but the center 4 trees used as buffers to spray drift.

Spray application. All treatments were applied with an engine-driven airblast sprayer (FMC Model 1087) with a high volute boom at 130 psi and at 1.5 mph. A summary of delivery system specifications are represented in Table 2. Sprays were applied on 17 and 18 July after the morning dews had evaporated from the foliage. Temperature ranged from 90 to 95°F and relative humidity ranged from 72 to 100% under partly cloudy skies. Scattered evening showers produced less than 1 inch of rainfall 72 hr after spray application. Wind speed was negligible.

The macrocyclic lactone, abamectin (Agri-mek® 0.15 EC) and the insect growth regulator (IGR) diflubenzuron (Micromite 25W) were selected as acaricides based on previous efficacy data for citrus rust mite (8, 11, 13). Abamectin was applied at 0.0125 lb. a.i./acre plus 1 gal of FC-435-66 petroleum spray oil per acre in 25, 50, 100, and 500 gal of water (pH 7.8). Diflubenzuron was applied at a rate of 0.3125 lb. a.i./acre in the above quantities of water per acre.

Procedures for estimating citrus rust mite populations. Adult citrus rust mites were estimated on the fruit surface by counting the number of mites within a 0.16 inch^2 area at 2 locations on 2 sides of 25 fruit per plot at eye level (4 to 5 ft) with a gridded 10X hand lens at one wk prior to treatment and at 1, 2, 4, 6, 9, 11, and 13 wk post-treatment. Mite counting was always on the 4 center trees of each

Table 2. Summary of delivery system specifications for citrus rust mite test at Lake Wales, FL 1987.

Sprayer type	Rate gal/acre	Rate gal/tree	Delivery gal/min	Disc/core no.
	500	6.94	45.54	5.0/17
FMC Model 1087	100	1.38	9.17	2.5/17
speed sprayer w/volute	50	0.69	4.55	2.5/9
	25	0.34	2.31	2.5/5

Table 1. Effect of a constant rate of different acaricides applied at different spray volumes per acre on the residual control of the citrus rust mite on 'Valencia' orange at Lake Wales, FL, 1986.

Acaricide and rate	Spray volume (gal/acre)	Mean number mites/cm^2 on fruit[y]							Cumulative mite days
		wk: pre (–) and post (+) treatment							
		–1	0	+2	+4	+6	+8	+10	
Abamectin 0.15EC[z]	500	12.3	S	2.5	3.3	2.7	1.6	2.2	140 c
(0.0125 lb. a.i./acre)	100	15.1	P	2.8	10.0	3.9	1.8	0.8	246 c
	50	10.6	R	4.0	8.6	4.6	2.1	0.7	247 c
	25	6.8	A	0.4	1.7	1.3	0.7	0.5	58 a
Ethion 4EC	500	6.8	Y	0.0	0.4	0.4	1.0	1.2	34 a
(3.4 lb. a.i./acre)	100	12.2		0.2	0.8	1.6	1.8	3.8	87 b
	50	10.9	A	0.7	1.0	2.0	1.0	2.0	71 ab
	25	9.5	P	0.2	0.3	0.9	1.5	1.1	50 a
Chlorpyrifos 4EC	500	5.4	P	0.2	3.6	7.3	5.8	6.1	278 c
(2.5 lb. a.i./acre)	100	7.6	L	1.1	7.2	13.2	7.1	3.3	415 d
	50	7.9	I	0.9	2.9	8.3	6.0	4.2	277 c
	25	4.8	C	0.1	2.9	5.2	5.7	6.2	237 c
Fenbutatin oxide 4L	500	3.3	A	0.1	0.1	0.0	0.0	0.1	2 a
(1.3 lb a.i./acre)	100	11.5	T	0.0	0.2	0.3	0.5	1.6	25 a
	50	3.5	I	0.0	0.5	0.1	0.2	0.7	17 a
	25	9.5	O	0.1	0.2	0.4	0.3	1.0	21 a
Check	—	10.9	N	19.1	18.1	10.5	6.6	2.0	641 d

[z]Abamectin 0.15E applied with 1 gal of FC-435-66 petroleum oil (0.25%).
[y]Treatments replicated 4 times. Means based on 25 fruit/replicate. Means followed by the same letter are not significantly different at the 5% level of probability using Duncan's Multiple Range test.

plot. Mite time units designated as "mite days" were calculated using the following formulae:

$$MD: = \frac{PD1 + PD2}{2} \times SI$$

and

$$CMD = \sum_{i=1}^{4} MD;$$

where MD: = mite days; i = 1, 2, 3, and 4,
PD1 = mean population density for sample date 1,
PD2 = mean population density for sample date 2,
SI = number of days between sampling dates, and
CMD = cumulative mite days.

Mean mite population density per 0.16 inch^2 of fruit surface at each sample time and cumulative mite day values per treatment were tested for differences using Duncan's Multiple Range test.

Procedures for estimating percent fruit injury. The percent fruit per tree with visible citrus rust mite injury was determined immediately after the last mite population estimate. Counts were made with the aid of a 2.0 ft square frame which was positioned at a height of ca. 6.0 ft and near to the outer foliage of the tree (22). Each fruit within an imaginary tunnel extending from the frame to the center of the tree was examined for the presence of mite injury. For each treatment, 4 frame counts, one at each quadrant, were taken per tree with a total of 16 trees per treatment.

Field Test—1988

Experimental design. The experiment was conducted in the same grove with the same plot design as the 1987 field test, however, different trees were used in this test. Twenty treatment combinations (4 acaricide rates, 5 spray volumes) plus an unsprayed control were arranged in a randomized block design and replicated 4 times.

Spray application. All treatments were applied with an engine-driven airblast sprayer (FMC Model 1087) with a high volute boom (18). A schematic diagram of the sprayer and application conditions and summary of delivery system specifications are represented in the preceding paper (18).

A new formulation of dicofol (Kelthane MF) specifying less than 0.1% of DDT related impurities was selected as the experimental acaricide based on previous efficacy data for citrus rust mite. Four treatment rates, 0, 2, 4, and 6 pints of formulated Kelthane MF were each mixed with 6 lbs. of cupric hydroxide (50% metallic copper) in 50, 100, 250, 500, and 1000 gal of water, respectively. Prior to spraying, 1 pint of Triton AG-44M spray adjuvant was added to the tank mix to lower the pH to 7. Dicofol was applied at different rates/acre at sprayer ground speeds of 1.3 mph for the spray volume of 1000 gal/acre and 1.5 mph for the other volumes.

Procedures for estimating citrus rust mite populations on fruit. Adult citrus rust mites were estimated on the fruit surface for all treatment combinations using the same methodology described in the 1987 field test. Monitoring times were 1 wk pretreatment and 2, 4, 6, 8, and 10 wk post-treatment.

Procedures for estimating citrus rust mite populations on leaves. Adult citrus rust mite populations were also monitored on leaves at different locations within the tree canopy only in treatments with the full rate of dicofol and the untreated to determine the relationship between foliar coverage at different spray volumes (18) and mite control. As described in detail in the previous paper, 3 leaves were collected from a directional quadrant of 4 adjacent trees at heights of 5 and 10 ft and at radii, outside and 2 ft inside the tree canopy per plot. Leaf samples from each location were placed in zip-lok® plastic bags and placed in a cooler to prevent overheating. In the laboratory, the number of adult citrus rust mites per leaf were counted with a stereomicroscope.

Results

Field Test—1987. According to the results presented in Table 3, no significant difference in initial mortality or residual control of the citrus rust mite on fruit was found between spray volumes ranging from 25 to 500 gal/acre. The lack of relationship between spray volumes is reflected in both cumulative mite days and percent fruit injury. The acaricide, abamectin, gave significantly better residual control than the untreated check (Table 3). Where diflubenzuron was used as the acaricide, mite control appeared to be significantly better at 25 to 50 gal/acre compared to 100 to 500 gal/acre based on cumulative mite days and percent fruit injury (Table 4). This suggests that overall coverage was better at 25 to 50 gal/acre which resulted in slightly better residual control at 9 wk when mite populations in the untreated check were at a peak.

Table 3. Effect of a constant rate of Abamectin[z] applied at different spray volumes per acre on the residual control of the citrus rust mite and percent russet to 'Valencia' orange at Lake Wales, FL, 1987.

Spray volume (gal/acre)	Mean number mites/cm^2 on fruit[y]									Cumulative mite days	%[x] fruit injury
	wk. pre (−) and post (+) treatment										
	−1	0	+1	+2	+4	+6	+9	+11	+13		
500	2.3 a[w]	S	0.1 a	0.1 a	1.9 a	2.8 a	9.1 b	5.0 b	1.8 a	319 a	5.0 a
100	1.6 a	P	0.1 a	0.1 a	0.7 a	3.2 a	2.6 a	1.0 a	0.2 a	128 a	3.0 a
50	6.0 a	R	0.1 a	0.1 a	1.8 a	2.2 a	9.2 b	5.5 b	1.3 a	312 a	5.0 a
25	2.5 a	A	0.0 a	0.0 a	0.3 a	0.3 a	3.1 a	5.1 b	0.8 a	143 a	3.0 a
0	3.4 a	Y	3.1 b	6.1 b	21.6 b	37.3 b	35.7 c	9.9 c	2.2 a	1809 b	55.0 b

[z]Abamectin 0.15 EC applied at a rate of 0.0125 lbs. a.i./acre plus 1 gal of FC-435-66 petroleum oil (0.25%).
[y]Means based on 25 fruit sampled from each of 4 replications.
[x]Means based on 4 readings per tree, 16 trees per treatment.
[w]Means in columns followed by the same letter are not significantly different at the 5% level of probability using Duncan's Multiple Range test.

Table 4. Effect of a constant rate of diflubenzuron[z] applied at different spray volumes per acre on the residual control of the citrus rust mite and percent russet to 'Valencia' orange at Lake Wales, FL, 1987.

Spray volume (gal/acre)	Mean number mites/cm² on fruit[y]									Cumulative mite days	%[x] fruit injury
	wk. pre (–) and post (+) treatment										
	–1	0	+1	+2	+4	+6	+9	+11	+13		
500	2.2 a[w]	S	0.9 a	1.0 a	3.0 b	1.8 a	10.6 b	5.6 b	1.6 a	362 ab	17.0 b
100	6.0 a	P	0.8 a	2.0 a	3.0 b	4.8 b	12.9 b	6.4 b	1.3 a	484 b	18.0 b
50	2.7 a	R	0.9 a	1.0 a	1.5 a	2.1 a	3.2 a	2.0 a	0.8 a	161 a	14.0 ab
25	2.8 a	A	1.7 a	1.6 a	4.2 b	3.2 ab	4.3 a	4.9 b	1.0 a	288 a	10.0 a
0	3.4 a	Y	3.1 b	6.1 b	21.6 c	37.3 c	35.7 c	9.9 c	2.2 a	1809 c	55.0 c

[z]Diflubenzuron 25W applied at a rate of 0.3125 lbs. a.i./acre.
[y]Means based on 25 fruit sampled from each of 4 replications.
[x]Means based on 4 readings per tree, 16 trees per treatment.
[w]Means in columns followed by the same letter are not significantly different at the 5% level of probability using Duncan's Multiple Range test.

Field Test—1988. Residual control of the citrus rust mite on fruit, expressed as cumulative mite days from the time of treatment to 10 wk post-treament, is presented for each combined spray volume and acaricide rate (Table 5). No significant difference in the residual control of citrus rust mite at 10 wk post-treatment by dicofol was found between spray volumes ranging from 50 to 1000 gal/acre for all acaricide rates ($F = 0.88$; df = 4, 57; $P = 0.48$). However, residual control (cumulative mite days) was significantly affected by different rates of dicofol ($F = 10.20$; df = 3, 57; $P < 0.01$). No significant interaction between spray volume and acaricide rate was detected by F test statistical analysis ($F = 0.30$; df = 12, 57; $P = 0.99$) indicating that dicofol rate affected the control of citrus rust mite regardless of the change in spray volume. As expected, residual mite control increased with an increase in acaricide rate from 0 to 4 pints per acre, however, for some unexplainable reason, the 6 pints per acre rate of dicofol was least effective. This quadratic relationship between rate and residual control (mite days at 10 wk post-treatment) is consistent among spray volumes although the relationship is weak ($R^2 = 0.30$). No explanation for this difference in rate response can be given since the 6 pints/acre rate was determined to be most effective in research and development studies. Overall, the 4 pints/acre rate at 50 gal/acre was most efficacious suggesting that smaller droplet size and less pesticide runoff was responsible for the lowest mite day cumulation of 5.9.

Residual control of the citrus rust mite on leaves at different locations of the canopy at the 6 pints/acre rate at different spray volumes was not significantly different due to high variability in mite population density among samples (25.1 to 160.5 cumulative mite days) (Table 6). The non-significant ANOVA results indicate that this variability overpowered the effect of spray volume. Interestingly, the cumulative mite days in the copper-treated check (179.5) was significantly lower ($t = 2.08$; df = 90; $P = 0.04$) than in the check (296.1) without copper but was significantly higher ($t = 4.59$; df = 743; $P < 0.01$) than in the acaricide treatments (84.4) (Table 6).

By comparison, residual mite control for all spray volumes was significantly better in the upper canopy (10 ft) compared to the lower canopy (5 ft) ($F = 4.26$; df = 1, 12; $P = 0.04$) (Table 7). However, overall spray volume comparisons of cumulative mite days showed no significant difference, except for the 500 gal volume/acre where residual control was significantly different between outside and inside, and between the upper and lower canopy (Table 7). The differences in spray deposition within the tree canopy shown in the preceding paper (18) were absent for mite control probably because of the high variability in mite density on leaves.

Discussion

According to previously published research (20) and the data presented herein, spray volume has no significant effect on initial mortality and residual control of citrus rust mite even though higher spray volumes showed more uniform foliar coverage (18) and spray deposition varied within the tree. Though not conclusive, data trends suggest that lower spray volumes (25 to 100 gal/acre), when applied under normal conditions, are highly effective for the contol of rust mites on fruit. Published research suggests that reasons for this phenomenon are most likely related to mite distribution on the tree (20), uniform deposition of smaller spray droplets on the fruit, less coalescence of droplets on fruit (less runoff) and a higher contact fre-

Table 5. Residual control of citrus rust mite on fruit expressed as mean cumulative mite days at 10 wk post-treatment at different spray volumes and acaricide rates at Lake Wales, FL, 1988.

Acaricide rate (pint/acre)	Spray volume (gal/acre)					Mean[z]
	50	100	250	500	1000	
0	182.2	212.3	216.1	150.5	276.0	207.4 a
2	52.2	73.5	77.1	87.5	74.9	74.0 b
4	5.9	70.9	75.2	32.7	46.6	46.3 b
6	48.8	122.3	88.9	117.5	136.0	102.7 b
Mean	73.5	119.7	114.3	97.0	133.4	

[z]Means followed by the same letter are not significantly different at the 5% level of probability using Duncan's Multiple Range test.

Table 6. Residual control of citrus rust mite on leaves expressed as mean *cumulative* mite days at 6 wk post-treatment at different spray volumes and acaricide rates at Lake Wales, FL, 1988.

	Acaricide rate (pint/acre)	
Spray volume (gal/acre)	0	6
50	97.1	66.0
100	141.4	92.2
250	248.6	25.1
500	165.1	160.5
1000	236.2	83.0
ANOVA	F = 2.85 df = 4,328 P = 0.02	F = 1.74 df = 4,333 P = 0.14 N.S.

Table 7. Residual control of citrus rust mite on leaves expressed as mean cumulative mite days at different locations in the tree canopy, Lake Wales, FL, 1988.

	Canopy depth (radii)		Canopy location (height)	
Spray volume (gal/acre)	Inside	Outside	Upper (10 ft)	Lower (5 ft)
50	39.0	91.6	45.4	90.3
100	38.2	133.7	22.8	156.3
250	26.4	21.2	28.6	19.6
500	217.3	99.7[z]	102.3	213.2[z]
1000	92.3	66.2	92.8	76.5

[z]Significantly different at $\alpha = 0.05$ using paired t test.

quency with the mite or the plant surface inhabited by the mite (19). The authors have observed coalescence of droplets at higher spray volumes that result in large patches of fruit surface void of pesticide film. Therefore, it is imperative that the applicators recognize the importance of sprayer calibration, define weather conditions for spray application and the nature of the target before venturing into low volume spraying.

These data also showed that the residual control of citrus rust mite differs according to acaricide, yet the efficacy of most acaricides is so good, that they might compensate for lesser coverage in some regions of the tree canopy and on the fruit itself. The secret to optimum mite control appears to be related to timing of application and optimum coverage related to droplet size on the target.

The data presented herein on rate response to spray volume/acre suggest that rates lower than the recommended rate might give acceptable residual control of citrus rust mite. Less spray runoff and more thorough coverage might equate to less pesticide/acre. However, more research is needed comparing rate to spray volume/acre.

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