Reprinted from
Proc. Fla. State Hort. Soc. 114:111-118. 2001.

SPRAY VARIABLE EFFECTS ON DEPOSITION AND HARVESTING EFFICACY OF CMN-PYRAZOLE

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Additional index words. Spray volume, 5-chloro-3-methyl-4-nitro-1*H*-pyrazole, Pyranine, fruit detachment force, trunk shaker, Citrus.

Abstract. **The renewed interest in mechanical harvesting of Florida citrus has intensified the investigations on using abscission chemicals to enhance fruit loosening and assist mechanical harvesting. Four tests were conducted using 5-chloro-3-methyl-4-nitro-1*H*-pyrazole (CMN-pyrazole) in two commercial orange groves in central and south Florida. In Tests 1 and 2 the spray was delivered at different flow rates to the top and bottom halves of 'Hamlin' orange tree canopies. The other two tests were conducted in 'Valencia' orange grove. In Test 3, spray application variables were sprayer type, spray volume, and application time. In Test 4, spray application variables were sprayer type and spray release height. Spray deposition was assessed by fluorometry and the abscission chemical efficacy was quantified by measuring the fruit detachment force and the percent of fruit removed by a trunk shaker. Spray release height had a significant effect on spray deposition along the canopy height. However, deposition at different canopy heights was not proportional to spray delivery rate directed to different heights. Depositions on the outside and at the canopy edge were generally higher than those on the inside and at the tree center. In general, spray release height had significant effects on fruit loosening and removal. Deposition decreased with increased application volume, but higher application volume produced better effects on fruit loosening and removal. At low volume, night time application resulted in higher deposition than daytime application.**

Several studies have evaluated the efficacy of abscission chemicals in relation to mechanical harvesting of oranges. Hedden et al. (1988) reported that abscission chemicals enhanced fruit removal efficiency of trunk shakers by 17 to 26 percentage points. Koo et al. (1999) studied the effects of sprayer type, spray volume, and CMN-pyrazole (CMN-P) application rate on spray deposition and abscission efficacy. The study reported that spray variables could affect deposition and penetration. Deposition varied with volume rate and canopy location. Fruit loosening and removal efficiency increased at higher volume rates. Whitney et al. (2000a) studied the effects of spray application and shaker operation variables on fruit loosening and removal efficiency. They reported that variable spray release to the top and bottom half sections of the tree could affect fruit loosening and removal efficiency and a linear shaking pattern resulted in 1 to 6 percentage points better fruit removal efficiency than a multidirectional shaking pattern. Whitney et al. (2000b) studied the fruit removal efficiency of four trunk shakers and three abscission chemicals on 'Hamlin' and 'Valencia' oranges [(*Citrus sinensis* (L.) Osbeck)]. Removal efficiencies were increased by 10 to 15 percentage points while orange detachment forces were reduced by 50 to 80% compared with unsprayed controls.

Application variables have been found to affect spray deposition and pesticide efficacy in citrus tree canopies. Salyani et al. (1988) studied the effect of volume rate on spray deposition using a copper tracer. The study showed that volume rate had no significant effect on mean copper deposition, but higher volume rates resulted in more uniform coverage than lower volume rates. Hoffmann and Salyani (1996) studied the effect of application time on spray deposition and uniformity. They concluded that night time application resulted in more deposition than daytime application.

The objectives of this study were:

1. To investigate the effects of spray application variables (sprayer type, spray volume, application time, and spray release height) on deposition of an experimental abscission chemical CMN-pyrazole.

2. To evaluate the efficacy of the abscission chemical in loosening the fruit for mechanical harvesting.

Materials and Methods

'Hamlin' Studies (Tests 1 and 2)

Spray applications. Two tests were conducted in a commercial 'Hamlin' orange grove in Lake Alfred, Fla., on 6 Jan. and 11 Feb. 2000. The purpose of the tests was to determine spray deposition and fruit removal efficacy of the abscission chemical when applied at different rates to the top and bottom halves of tree canopies. The spray mixture contained an experimental abscission chemical CMN-pyrazole [Release®, 17.18% a.i. (w/w) Abbott Laboratories, Chicago, Ill.] at an a.i. rate of 100 mg L^{-1}, surfactant (Kinetic®, Setre Chemical Co., Memphis, Tenn.) at 0.1% v/v, and a tracer for spray deposition assessment [Yellow Fluorescent Pigment (SARDI, Loxton, South Australia) and Pyranine-10G (Keystone Aniline Inc., Chicago, Ill.) in Tests 1 and 2, respectively]. In both tests, spray treatments and unsprayed control (check) treatment were assigned in a randomized complete block design and replicated four times. For each treatment, the spray was applied to both sides of 3-tree plots. The trees were about 5.0 to 5.5 m high and spaced at 7.6 by 3.7 m. Sprays were delivered with an air-blast tower sprayer (Titan 1093, John Bean Sprayers, Hogansville, Ga.), equipped with an axial flow fan, tower air-duct, and 34 hydraulic nozzles per side. The treatments consisted of three spray delivery (nozzle) arrangements:

This research was supported by the Florida Agricultural Experiment Station and a grant from the Florida Dept. of Citrus, and approved for publication as Journal Series No. N-02077. The authors thank Gapway Grove Crop. and Davis Enterprises, Inc. for providing test groves, Dr. Ramon C. Littell for statistical consultation, and Roy D. Sweeb, David C. Noxel, and Gerald D. Perkins for their technical assistance. mention of specific products is for information purposes only and does not imply recommendation of the products by the University of Florida over those not mentioned.

a) *T3B1*, i.e., ¾ of spray volume was discharged from the top 17 nozzles, at 3.0-5.2 m height, and directed to upper half of the canopy (¼ of spray volume from the bottom 17 nozzles, at 0.9-2.9 m height, to the lower half of the canopy),

b) *T2B2*, i.e., spray was discharged uniformly along sprayer height (0.9-5.2 m), and

c) *T1B3*, i.e., ¼ from the top—¾ from the bottom nozzles (reverse of the T3B1).

The application variables of the spray treatments are shown in Table 1.

After spraying, leaf samples were collected from both sides of the middle tree at three heights (1.5, 3.0, and 4.5 m) and at two depths (outside and about 60 cm inside the tree canopy). Koo et al. (1999) reported a strong correlation between leaf and fruit deposition; therefore, fruit samples were not collected. Leaf samples were washed with de-ionized water and fluorescent deposits were measured with a fluorometer (Model 111, Sequoia-Turner Co., Mountain View, Calif.). Leaf areas were measured using an area- meter system (Delta-T Devices Ltd., Cambridge, UK). CMN-pyrazole (CMN-P) deposition was determined from that of the tracer.

Mechanical harvesting. Four to 5 d after spraying, fruit detachment force (FDF) was measured with a force gauge (Model FDV-50, Wagner Instrument, Greenwich, Conn.), on five oranges in each of the top and bottom half tree sections. Then the middle tree of each plot was shaken with a trunk shaker (Orchard Rite, Yakima, Wash.). The shaker was set to a multidirectional shake pattern with 255 and 205 kg of unbalanced mass in Tests 1 and 2, respectively (Whitney et al., 2000a). Trunk displacement was measured on representative trees with an accelerometer-data-acquisition system (PCB piezotronics, Inc., Depew, N.Y.) and DaqBook (Iotech, Cleveland, Ohio). The trees were shaken for approximately 10 s at 7 Hz. For each treatment, fruit removed by the shaker and fruit that remained on the tree were weighed separately to determine the percentage of fruit removed. Trunk circumference and the shaker clamp height were measured for each shaken tree. These measurements were used to test the correlations between tree factors and fruit removal efficiency.

'Valencia' Studies (Tests 3 and 4)

Spray applications. Two field tests were conducted in a commercial 'Valencia' orange grove near Crewsville, Fla., on 27 Apr. and 19 May 2000. Specific objectives were to determine the deposition and fruit removal efficacy of the abscission chemical at two volume rates and two times (Test 3), and three spray release heights (top half, bottom half, and both halves of the spray manifold) (Test 4). In both tests, CMN-P was used as the abscission chemical and Pyranine-10G as the deposition tracer. The treatments were assigned as randomized complete block to 4-tree plots. The trees were about 4.6-5.5 m high and set alternately at 3.0 m and 4.6 m spacings.

Spray equipment included the Titan and standard 8-fan Curtec (BEI, Inc., South Haven, Mich.) sprayers. The latter, equipped with cross-flow fans and rotary atomizers (one atomizer per fan), is commonly used for spraying citrus at low-volume rates (140-280 L ha^{-1} at 3.2-8.0 km h^{-1}). Both sprayers were used at different combinations of operating variables. In Test 3, spray treatments were defined by combinations of volume rate and application time: low volume-daytime (LV-D), low volume-night time (LV-N), high volume-daytime (HV-D), and high volume-night time (HV-N). Spray treatment variables in Test 3 are shown in Table 2. In Test 4, sprays were applied at 1028 L $ha^{-1}$and 4.8 km $h^{-1}$and the treatments consisted of: a) uniform discharge along the canopy height (T2B2), b) all to the top half section of the canopy (T4B0), and c) all to the bottom half section (T0B4). The above treatments were applied with 20 D6-23 nozzles (Titan) and 4 (or 2 × 2) rotary atomizers (Curtec). CMN-P and the tracer concentrations were 375 and 350 mg L^{-1}, respectively.

In Test 3, leaf samples were collected from the two middle trees of each plot, as described in the 'Hamlin' studies. However, in Test 4, deposition (spray penetration) was sampled with absorbent cotton ribbons (2.5 cm wide) placed at the tree row line about 30 and 120 cm from the tree trunk. The ribbons were stretched from the ground level to the canopy top. After spraying, the cotton ribbons were cut into 60-cm long segments and stored individually in sampling bags. Deposition was determined by measuring fluorescence of wash solutions.

Mechanical Harvesting. Fruit detachment forces and fruit removal variables were measured as described in the 'Hamlin' studies, except that the two middle trees of each plot were shaken to determine fruit removal efficiency. Trees were shaken in a linear pattern for 5 s at 7 Hz with 205 kg of unbalanced mass. Trunk displacement was about 6 cm.

Data collected from both studies were analyzed using the GLM procedure in SAS (SAS, 1990). Means were separated at the 5% level of significance using the Duncan's multiple range test. Shaker removal data were correlated with fruit detachment force, spray deposition, trunk circumference, and clamp height data using the Pearson correlation analysis.

Results and Discussion

'Hamlin' Studies (Tests 1 and 2)

Spray deposition. In both tests, there was no significant difference in overall canopy deposition between different spray treatments (Figs. 1 and 2). The deposition at different canopy heights followed the expected trend (higher deposition at higher discharge rate) in the first test but not in the second

Table 1. Application variables of spray treatments in 'Hamlin' studies (Tests 1 and 2).

Test[z]	Volume at (L ha^{-1})	Ground speed (km h^{-1})	Yellow pigment (ml L^{-1})	Pyranine (mg L^{-1})	Treatment code	Nozzles on top half manifold	Nozzles on bottom half manifold	Operation pressure kPa
Test 1	3750	2.6	1.51	—	T3B1	17, D6-25[y]	17, D4-23[y]	807
					T2B2	17, D4-25	17, D4-25	1076
Test 2	2450	4.0	—	350	T1B3	17, D4-23	17, D6-25	807

[z]Applied with Titan sprayer.
[y]Spraying Systems, Co., Wheaton, Ill.

Table 2. Application variables of spray treatments in Test 3.

Treatment code[z]	Volume rate (L ha^{-1})	Spray time	Ground speed (kg h^{-1})	CNM-P a.i. (mg L^{-1})	Pyranine (mg L^{-1})	Titan nozzles	Nozzle pressure (kPa)	Curtec[x] gpm index
LV-D	234	Day	4.8	1650	1500	12, TXVK-6[y]	793	1.80
HV-D	1540	Day	3.2	250	227	12, TXVK-6 and 13, D4-25	1048	11.20
LV-N	234	Night	4.8	1650	1500	12, TXVK-6	793	1.80
HV-N	1540	Night	3.2	250	227	12, TXVK-6 and 13, D4-25	1048	11.20

[z]Applied with both Curtec and Titan sprayers.
[y]Spraying Systems, Co., Wheaton, Ill.
[x]All four atomizers of the Curtec sprayer were open.

test. The magnitude of deposition along the canopy was not proportional to spray delivery rates directed to different heights. However, in both tests, higher depositions were observed at the 1.5 m height and lower depositions were observed at the 4.5 m height for treatment T1B3. Accordingly, treatment T3B1 had lower depositions at the 1.5 m height and higher depositions at the 4.5 m level. Treatment T2B2 resulted in a somewhat uniform deposition along the canopy height in the first test but not in the second test. In both tests, depositions were higher and less variable (lower coefficients of variation, CV) in the outside than in the inside canopy locations.

The disproportionate depositions at different heights could in part be attributed to variable sprayer air velocity, excessive runoff, and different canopy structures along the canopy height (Salyani et al., 2001). The increase in ground speed from 2.6 km ha^{-1} (Test 1) to 4.0 km h^{-1} (Test 2) resulted in a reduction of the spray application rate from 3750 to 2450 L ha^{-1} that could have contributed to the reduction of spray runoff from the lower locations. Reduced spray runoff could have contributed to the higher overall deposition in the second test.

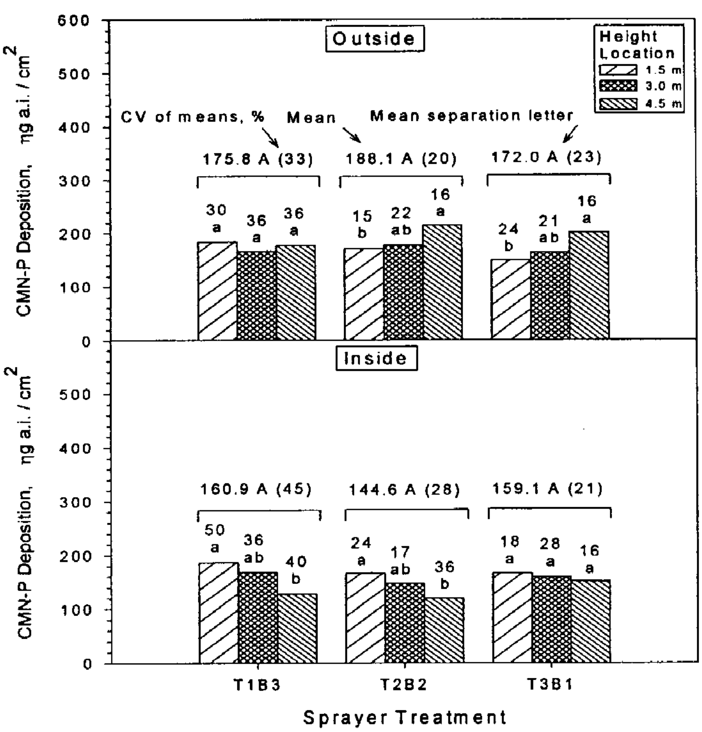

Figure 1. CMN-P deposition at different canopy locations in Test 1.

Mechanical harvesting. In Test 1, FDFs were significantly reduced by the spray treatments (Fig. 3). Fruit detachment forces of unsprayed trees were significantly higher in the upper than in the lower tree sections. Kender and Hartmond (1999) reported a similar observation. All spray treatments resulted in more even FDF between upper and lower tree sections. Despite significant difference in FDF among spray treatments, fruit removal was not affected significantly and varied from 91 to 95% (Fig. 4). The control had significantly lower fruit drop than the sprayed trees. The other fruit removal parameters such as clamp height, trunk circumference, and total fruit yield (Table 3) were not significantly different among all treatments.

In Test 2, spray treatments significantly reduced FDF (Fig. 3) with the exception of treatment T1B3. Except for treatment T3B1, all spray treatments also resulted in somewhat lower FDF in the lower tree sections. Unlike in the first test, spray treatments significantly improved fruit removal (93 to

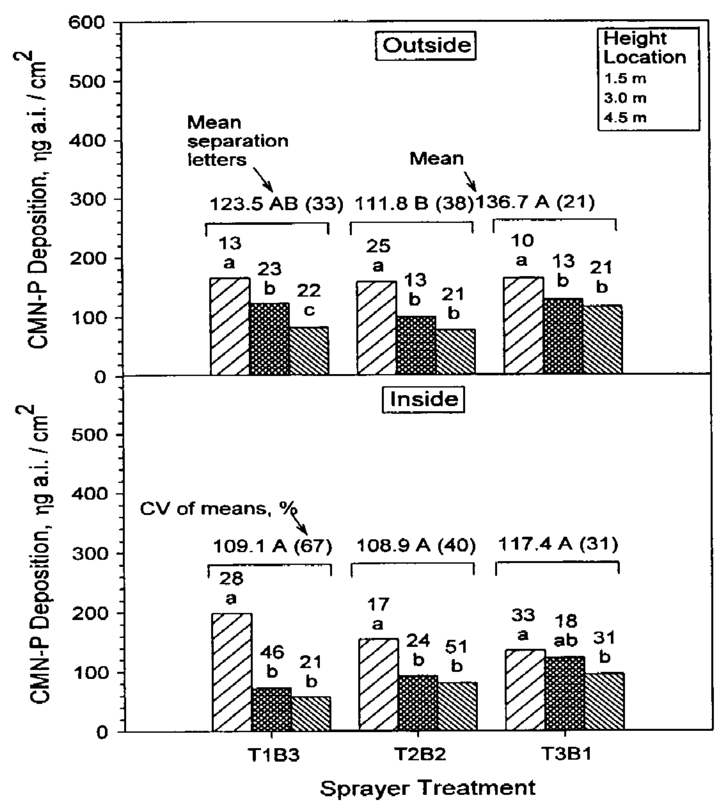

Figure 2. CMN-P deposition at different canopy locations produced by the spray treatments in Test 2.

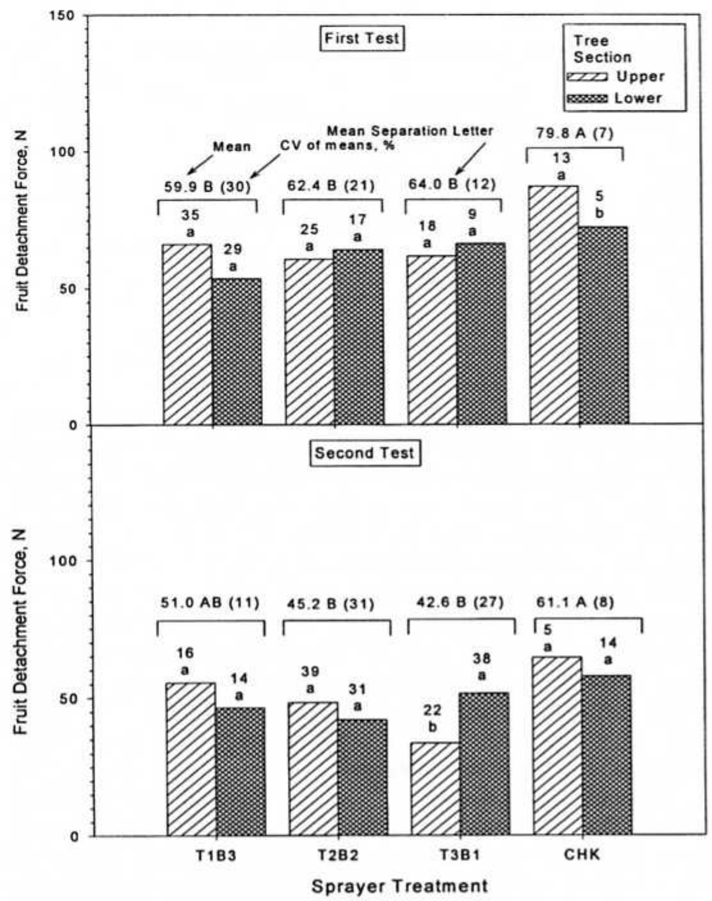

Figure 3. Spray treatment effect on fruit detachment force in Tests 1 and 2.

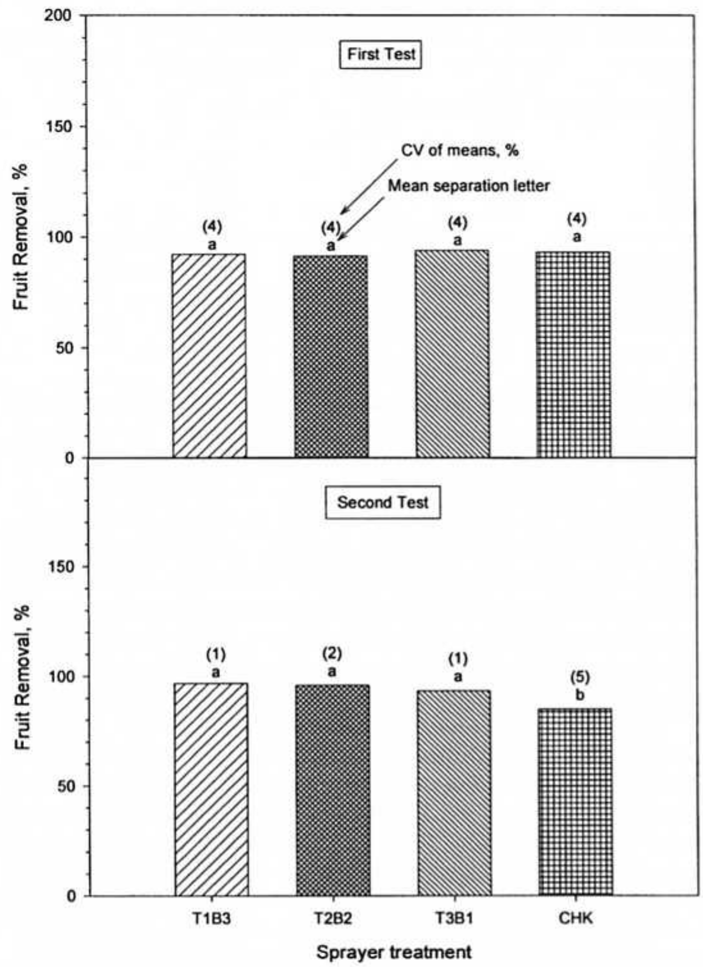

Figure 4. Spray treatment effect on fruit removal in Tests 1 and 2.

97%) in comparison with 85% in the control (Fig. 4). Trunk circumference and fruit yield (Table 3) were not significantly different among spray treatments. However, the shaker clamp height was significantly variable among the spray treatments. The pre-harvest fruit drop also varied significantly between the spray treatments and ranged from 0.7% for the unsprayed to 2.9% for the sprayed treatments.

In both tests, the Pearson correlation analysis (Table 4) showed a significant negative correlation between spray depositions and FDF. The correlation between spray deposition and fruit removal was significant only in the second test. In both tests although not statistically significant, there were negative correlations between fruit removal and detachment forces and trunk circumference, and positive correlations with shaker clamp height.

'Valencia' Studies (Tests 3 and 4)

Spray deposition. In Test 3, both sprayers gave higher depositions at the low volume than the high volume treatments (Fig. 5). Deposition was the highest for the low volume-night time treatment and the lowest for the high volume-night time

Table 3. Effect of spray treatments on fruit removal parameters in Hamlin studies.[z]

Treatment code	Fruit yield (kg)	Shaker clamp height (cm)	Trunk circumference (cm)	Fruit drop (%)	Fruit yield (kg)	Shaker clamp height (cm)	Trunk circumference (cm)	Fruit drop (%)
	Test 1				Test 2			
T1B3	228.0 a (7)	20.6 a (15)	78.1 a (2)	1.2 ab (35)	223.2 a (3)	23.5 ab (22)	1.7 bc (38)	77.2 a (1)
T2B2	231.8 a (9)	23.5 a (24)	73.0 a (6)	1.4 ab (32)	203.3 a (14)	26.1 a (12)	1.9 ab (30)	69.6 a (9)
T3B1	242.2 a (7)	22.9 a (30)	74.0 a (10)	1.5 a (36)	234.0 a (14)	18.1 b (9)	2.9 a (29)	74.3 a (8)
CHK	230.2 a (24)	22.2 a (7)	71.8 a (7)	0.6 b (82)	228.2 a (7)	19.7 b (19)	0.7 c (51)	75.6 a (21)

[z]Means followed by the same letter(s) in each column are not significantly different at the 5% level.

Table 4. Pearson correlation coefficients of variables with fruit removal in 'Hamlin' studies.

	Test 1		Test 2	
Variable	r	(P > r)	r	(P > r)
CMN-P deposition	-0.18	(0.50)	0.84	(0.001)
Fruit detachment force	-0.23	(0.39)	-0.39	(0.13)
Total fruit yield	-0.23	(0.08)	-0.34	(0.20)
Shaker clamp height	0.12	(0.65)	0.43	(0.09)
Trunk circumference	-0.10	(0.72)	-0.43	(0.09)

treatment. This result may be attributed to the higher relative humidity at night and wetness of the leaf surface. While the wetness of the leaf surface increased the retention capacity for fine sprays (produced at low volume) it reduced the retention capacity for coarser spray in high volume applications (Hoffmann and Salyani, 1996). Both volume rates applied identical amounts of CMN-P (0.39 kg ha^{-1}). However, low volume deposition averaged 1.4 times that of high volume. At either volume, sprayer type had no significant effect on overall deposition.

In Test 4, both sprayer types produced similar deposition patterns along the canopy height (Fig. 6), however, the Titan sprayer produced somewhat higher deposition than the Curtec sprayer. Even though all of the spray was aimed towards the lower half section of the canopy in T0B4, some

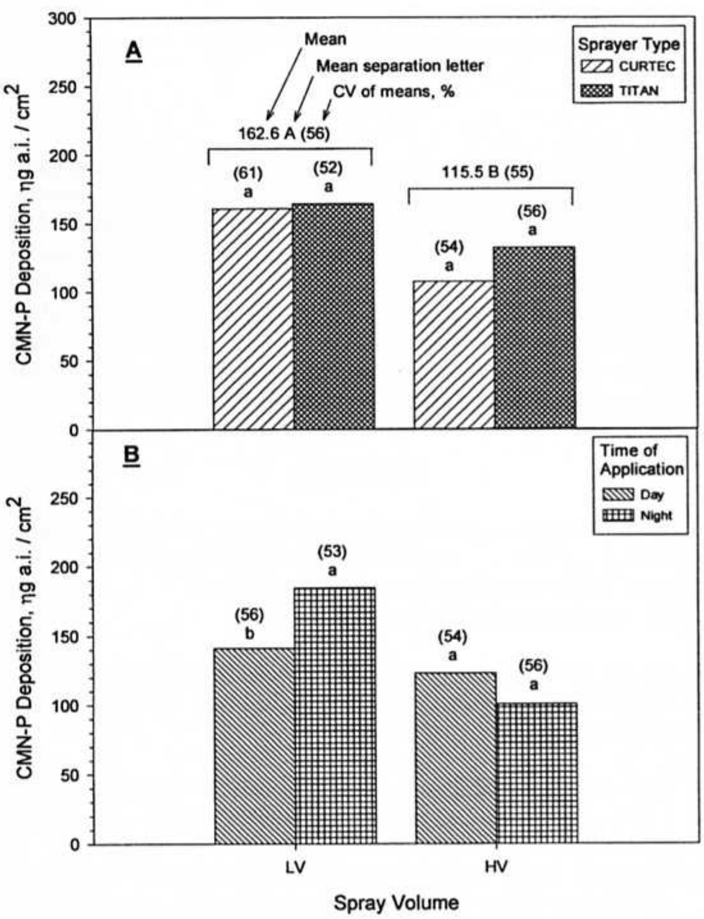

Figure 5. Overall spray deposition in Test 3, comparing **A** sprayers and **B** application times.

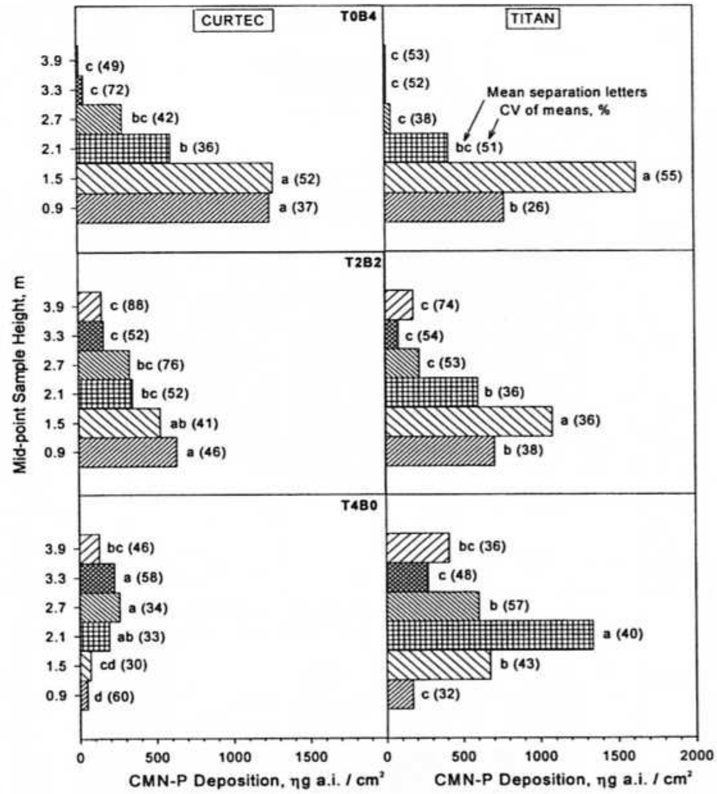

Figure 6. Spray deposition along the canopy, produced by the spray treatments in Test 4.

spray was deposited in the upper half section. Treatment T2B2, resulted in higher and more uniform depositions at lower canopy locations than those at higher levels, although spray was delivered uniformly along the canopy height. Treatment T4B0 resulted in a bell shaped deposition along height of the tree canopy. In all treatments, some spray relocation from the upper to lower canopy levels was observed. Such spray relocation is, most probably, due to spray runoff intercepted at lower canopy locations as suggested by Hoffmann and Salyani (1996).

Mechanical harvesting. In Test 3, except for high volume daytime application with the Titan sprayer, all treatments resulted in lower FDF in the lower canopy than in the upper section (Fig. 7). However, differences were not statistically significant. Compared to the unsprayed treatment, high volume application reduced FDF more than low volume application. Similar results were reported by Kender and Hartmond (1999) and Koo et al. (1999). At both volumes, the time of application did not significantly affect FDF. Except for the high volume night time applications, spray treatments had no significant effect on fruit removal (Fig. 8). The high volume night time application had the lowest overall deposition, but resulted in the lowest FDF and the highest fruit removal (91%). High volume and dew formation during night time application probably produced better fruit coverage and allowed better action of the abscission chemical.

In Test 4, all spray treatments reduced the FDF when compared with the unsprayed control (Fig. 9). However, the differences were significant only with the CURTEC sprayer. Except for treatment T4B0 of the Curtec sprayer, all treatments resulted in lower FDF in the lower section than in the