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## EFFECTS OF ABSCISSION CHEMICAL SPRAY DEPOSITION ON MECHANICAL HARVEST EFFICACY OF 'HAMLIN' ORANGE

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*Abstract.* An experimental abscission chemical, 5-chloro-3-methyl-4-nitro-1H-pyrazole (Release®, CMN-P), was applied to investigate the effects of spray variables on the mechanical harvesting efficacy of a trunk shaker on 'Hamlin' orange [*Citrus sinensis* (L.) Osbeck] trees. Spray test variables were sprayer type, spray volume and CMN-P application rate. A Titan tower sprayer delivered higher deposition and achieved better canopy penetration compared to the conventional FMC sprayer. Generally, spray deposition was lower in the upper than in the lower canopy section and lower in the inside than in the outside canopy position. Deposition increased with a decrease of spray volume, but high spray volumes resulted in lower fruit detachment force and higher percent removal of fruit than low spray volumes. The percent removal of fruit was positively correlated with application rates of CMN-P, uniformity of deposition, fruit rind 'burn' and pre-harvest drop of fruit.

### Introduction

Harvest labor is a major expense to the citrus growers, constituting about 40% of the total production cost in Florida

(Muraro, 1997). Rising harvesting costs and a changing labor market have revived the citrus industry's interest in mechanical harvesting alternatives to hand labor.

Research on different concepts of mechanical harvesters has been conducted since the late 1960's with emphasis on trunk shakers, limb shakers, foliage shakers, and air shakers (Whitney, 1995). In the same period, abscission chemicals were identified and evaluated for enhancing mechanical harvesting efficiency by loosening fruits. However, the use of abscission chemicals resulted in fruit blemishes, premature fruit drop, excessive leaf drop, residue problems, and inconsistent fruit loosening (Brown, 1998; Whitney, 1995). An experimental abscission chemical, CMN-pyrazole (Release®, Abbott Laboratories, Chicago, IL) was effective for loosening fruits, but was never registered (Hartmond et al., 1999; Whitney et al., 1999). A goal of our research group at the Citrus Research and Education Center in Lake Alfred, FL, is to develop abscission chemicals as an aid for the mechanical harvest of oranges (Kender et al., 1998; 1999; Whitney, 1998).

To be an effective fruit loosener, an abscission chemical must be deposited on the fruit which requires precise and efficient delivery of the chemical to the target. Earlier studies have shown that spray application parameters could affect the characteristics of deposition. Variability of spray deposition increased as spray volume decreased (Salyani and McCoy, 1989). Night applications gave higher deposition than daytime sprays as long as leaves were dry, but wet leaf surface reduced the deposition because of run-off particularly at higher volume rates (Salyani and Hoffmann, 1996). Lower spray volume gave higher deposition efficiency than high spray volume, but the variability of deposition increased as spray volume decreased. The percent retention of spray decreased when applied at spray volumes above 2000 L/ha (Cunningham and Harden, 1998). More time exposure to the air blast at slower ground sprayer speed reduced the retention because of the excessive blow-off of deposited materials.

The efficiency of fruit removal by shaking is related to fruit maturity and fruit detachment force (FDF) at the abscission zone on the peduncle (Coppock et al., 1969). Fruit detachment force of 'Hamlin' orange was generally lowest in the lower canopy sections, accentuating the need for adequate coverage of abscission material sprays in the upper canopy to insure uniform loosening (Kender and Hartmond, 1999).

The objective of the first study was to investigate the effect of sprayer type on abscission chemical deposition and mechanical harvesting efficacy. The second study was designed to determine the effects of spray volume and chemical application rate on the chemical deposition and harvesting efficacy in 'Hamlin' orange.

## Materials and Methods

### Study No. 1

Two identical field tests were conducted in a commercial grove, Lake Alfred, Florida on December 16, 1998 and February 5, 1999 to compare CMN-P efficacy of a conventional air-blast sprayer (FMC 9100, FMC Corp., LaGrange, GA) to an air-tower sprayer (Titan 1093, John Bean Sprayers, Hogansville, GA). Both sprayers had identical axial flow fan operated at the same rotational speed. The FMC sprayer utilized an axial fan and hydraulic nozzles that discharged radially toward the canopy. The Titan sprayer was equipped with an ax-

ial flow fan and tower air-duct that discharged spray-laden air over entire canopy height. The sprayers were calibrated to deliver an application rate of 1400 L/ha (150 gpa) at the speed of 3.2 km/h (2 mph) using 18 disc-core nozzles (Spraying Systems Co., Wheaton, IL) per side. Spray mixtures contained CMN-pyrazole abscission agent (Release®, 17.18% a.i.(w/w), Abbott Laboratories, Chicago, IL) at 100 mg/L a.i., (100 ppm) and Kinetic® surfactant (Setre Chemical Co., Memphis, TN) at 0.1% (v/v). Thus, CMN-P application rate was 140 g/ha (2 oz/a). Pyranine 10G fluorescent dye (Keystone Aniline Inc., Chicago, IL) at 500 mg/L was included as a tracer in the February 5 test.

The tests with the two sprayers and an untreated check were applied to 3-tree plots and were replicated 4 times (12 plots) in a randomized complete block design. 'Hamlin' orange trees in each plot were 5.5 to 6.0 m (18-20 ft) tall and spaced at 7.6 m (25 ft) by 3.7 m (12 ft).

For deposition measurements two fruit and several leaves were sampled in the February 5 test from the middle tree of each plot at 3 heights of 1.5, 3.0, and 4.5 m (5, 10, and 15 ft) from the outside (OUT) and about 60 cm (2 ft) inside (IN) of the canopy (6 locations). The sampling was completed within one and half hours after spraying. Leaf and fruit samples were washed with 100 mL of deionized water and the fluorescence levels in the wash water were measured using a fluorometer (Model 111, Sequoia-Turner Corp, Mountain View, CA). A preliminary test indicated the dye was relatively stable with less than 10% degradation after one hour under direct exposure to sunlight. Leaf area was measured using an area meter system (Delta-T Devices Ltd., Cambridge, UK) and 3 directional diameters of a fruit were measured to estimate fruit surface area.

Four days after spraying, fruit detachment forces (FDF) of five fruit were measured using a pull force gauge (Model FDV-50, Wagner Instrument, Greenwich, CT) at two heights (about 1.8 m and 4 m (6 ft and 13ft)) from the middle tree in each plot (12 plots × 2 heights × 5 fruit). On the following day (5 days after spraying), the middle tree of each plot (12 plots) was shaken using a trunk shaker (Fruit Harvesters International Inc., Alva, FL) for 5 sec at 6 Hz and 5 cm displacement, and the removed fruit was weighed. Remaining fruit on the tree were picked manually and weighed to determine harvesting efficiency as percent removal (PRMV) of fruit. The location of shaker clamp-pad and the tree trunk circumference were also recorded in both studies.

### Study No. 2

Two field tests were conducted in an adjacent commercial grove from study No. 1, Lake Alfred, Florida on December 10, 1998 and February 17, 1999 using a PTO driven air-blast sprayer (Pul-Tank®, Rear's Mfg. Co., Eugene, OR) and varying the levels of spray volume and CMN-P concentration. In the December 10 test, preliminary efficacy measurements were made without a dye-traced deposition test. Based on the results of the test the spray volume and concentration were increased, resulting in a 1.8 fold higher CMN-P application rates for the February 17 test (Table 1).

The objectives of study No. 2 were to investigate the effects of: (1) spray volume by comparing the treatments of low (A:560 L/ha), mid (C:1680 L/ha) and high (E:5050 L/ha) spray volumes at the same rate of CMN-P; and (2) CMN-P application rate by comparing the treatments of high (B:505 g/

Table 1. Treatment conditions of the 5 treatments (A-E) and an untreated check (F) conducted on December 10, 1998 and February 17, 1999 in study No. 2.

Treatment	Dec. 10			Feb. 17		
	Spray volume L/ha (gpa)	CMN-P a.i. conc. mg/L (ppm)	CMN-P app. rate g/ha (oz/a)	Spray volume L/ha (gpa)	CMN-P a.i. conc. mg/L (ppm)	CMN-P app. rate g/ha (oz/a)
A	470 (50)	300	140 (2.0)	560 (60)	450	253 (3.6)
B	1400 (150)	200	280 (4.0)	1680 (180)	300	505 (7.2)
C	1400 (150)	100	140 (2.0)	1680 (180)	150	253 (3.6)
D	1400 (150)	50	70 (1.0)	1680 (180)	75	126 (1.8)
E	4210 (450)	33.3	140 (2.0)	5050 (540)	50	253 (3.6)
F	0	0	0	0	0	0

ha), mid (C:253 g/ha), and low (D:126 g/ha) chemical rates at the same spray volume rate on the spray deposition and mechanical harvesting efficacy.

The sprayer was calibrated to the application rates presented in Table 1 at the speed ranges of 3.1-3.7 km/h (1.9-2.3 mph) using 12 Albuz® hollow cone nozzles (Norton Desmarquest, Vincennes Cedex, France) per side. Spray mixtures contained CMN-pyrazole abscission agent at the concentrations shown in Table 1 and Kinetic® surfactant at 0.1% (v/v). Pyranine 10G fluorescent dye was included as a tracer in the February 17 test.

The five treatments (A-E) and an untreated check (F) in Table 1 were applied to 3-tree plot and replicated 4 times (24 plots). 'Hamlin' orange trees in each plot were 3.6 m to 4.6 m (12-15 ft) tall and spaced at 7.6 m (25 ft) by 3.2 m (10.5 ft). One fruit and several leaf samples were taken to evaluate deposition in the February 17 test from the middle tree of each plot at heights of 1.8 and 3.6 m (6 and 12ft) from inside and outside of the canopy (IN, OUT) (4 locations). Four days after spraying, the number of fruit on the ground were counted to determine the pre-harvest drop (PDRP) of fruit prior to fruit detachment test in the February 17 test. Deposition and harvest results of FDF (24 plots × 2 heights × 5 fruit) and PRMV (24 plots) were evaluated as described for study No. 1.

For both studies, dye depositions (ng/cm<sup>2</sup>) on fruit (FDEP1) and leaves (LDEP1) were normalized to the same amount of applied dye per unit area (200g/acre) for determining a deposition efficiency index of spray application. The amount of CMN-P (µg/cm<sup>2</sup>) deposited on fruit (FDEP2) or leaves (LDEP2) was quantified from the dye deposition and was related to the mechanical harvesting efficacy. The means were separated using the PROC MIXED model of SAS with LSMEAN / PDIFF option (SAS, 1990; Littell, 1999).

## Results and Discussion

### Study No. 1

The FDF in the Titan sprayer treatment was lower than that in the FMC sprayer treatment in the December 16 test (Table 2). However, the PRMV were not statistically different. The FDF in the lower canopy was lower than that in the upper canopy (data not shown) as has been found previously in untreated 'Hamlin' oranges (Kender and Hartmond, 1999). Minimal fruit loosening occurred with the two spray treatments and was probably affected by cool daily high temperatures below 21°C (70°F) during and 3 days following the application. Wilson et al., (1977) made similar observations on the effect of cool temperature on the activity of CMN-P.

Results of the February 5 dye-traced deposition test are presented in Figures 1 and 2. Since the chemical application

rate remained the same in study No. 1, the quantitative deposition of CMN-P on leaves (LDEP2) and fruit (FDEP2) was proportional to the normalized dye deposition. This represented a deposition efficiency of spray application on leaves (LDEP1) and fruit (FDEP1). The leaf deposition (LDEP2) was strongly correlated with fruit deposition (FDEP2) (Pearson corr. coef. = 0.937, prob. = 0.019) (Fig. 4).

The mean depositions at different heights showed an interaction between the height and the sprayers. More deposition was measured in the lower canopy portion with the Titan sprayer, whereas the FMC sprayer deposited more spray in the upper canopy (Fig. 1-A). The different deposition distribution was due to different nozzle arrangements and air-blasting patterns of the two sprayers. About twice as much as material was deposited on the outside canopy than inside the canopy with the FMC sprayer, whereas 1.2-1.3 times more was deposited outside than inside with the Titan sprayer. Thus, the Titan sprayer achieved better canopy penetration depositing a larger portion of the spray to the interior compared to the FMC sprayer (Fig. 1-B).

The higher CMN-P deposition of the Titan sprayer at the lower height level resulted in lower FDF, compared to FDF in the upper canopy level (Fig. 2-A), whereas the mean FDF achieved with the FMC sprayer were not different between the heights. To compensate for the naturally higher FDF in the upper canopy, more abscission material should be directed in the upper canopy. The mean FDF achieved with the Titan sprayer was lower than that with the FMC sprayer (Fig. 2-B) due to higher depositions with the Titan sprayer. The higher deposition with the Titan sprayer was due to spray-laden air with the tower ducts, which was close to spray target of fruit, whereas the FMC sprayer delivered spray in long distance to upper canopy, losing significant portion of spray. However, the harvesting efficacy was not significantly different. The mean PRMV's for the FMC and Titan sprayer treat-

Table 2. Means and coefficients of variation (CV) in parentheses of fruit detachment force (FDF), percent fruit removal (PRMV) and yield of 'Hamlin' orange as affected by spray types (December 16, 1998 test in study No. 1).

Dependent variables	Treatment		
	FMC	Titan	Control
FDF, N	97.7a* (31)	83.7b (24)	94.1ab (23)
PRMV, %	84.9a (2)	80.8a (7)	81.3a (12)
Yield, kg	267.1a (18)	265.9a (8.3)	272.0a (14)

\*Means within each row followed by different letters indicate significant difference using LSD at 5% level.

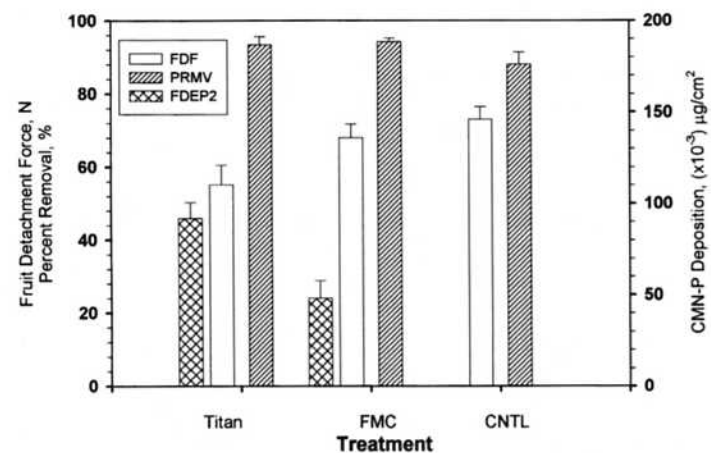
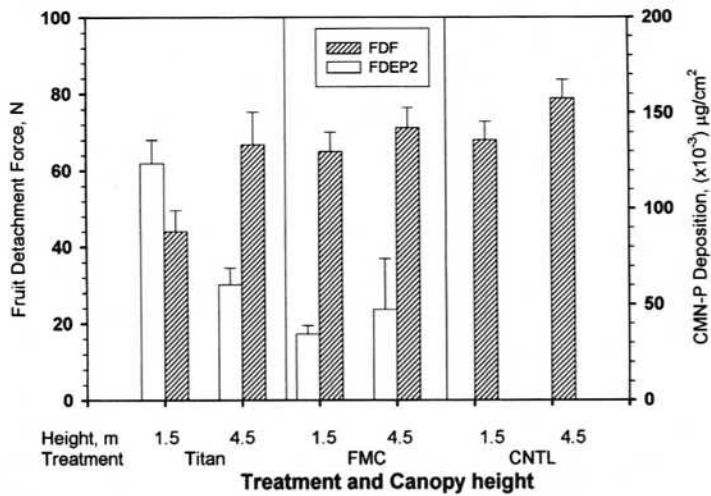
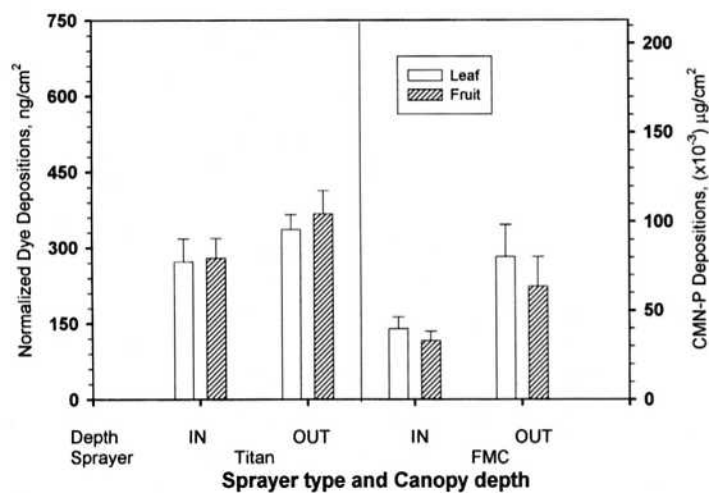
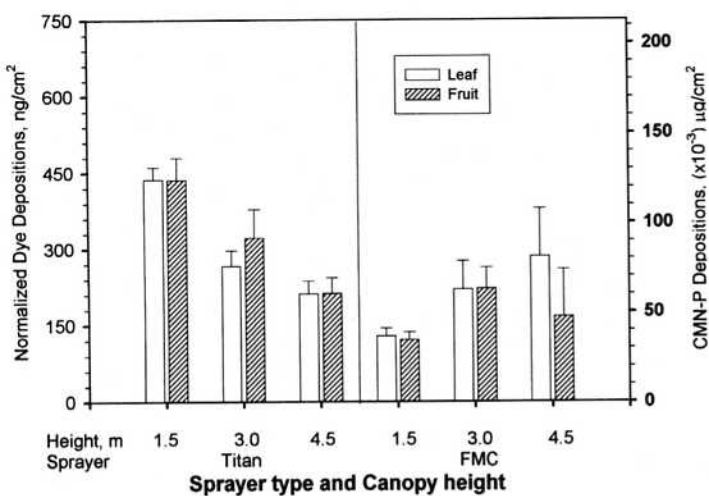


Figure 2. CMN-P chemical deposition, related to (A) the fruit detachment forces (FDF) at different canopy heights and (B) the percent removal (PRMV) for the treatments (February 5, 1999).

were 1.1-1.6 fold greater than those on the upper canopy. The dye depositions on the outside of the canopy were 1.6-1.8 fold greater than those inside the canopy (data not shown). These differences in spatial distribution were attributable to less uniform deposition over the canopy, especially in the low volume spray (A) treatment.

Based on dye-deposition, the low volume spray (A) also had higher CMN-P deposition than the high volume spray (Table 4) (E) because of the higher deposition efficiency or lower run-off. However, the FDF was low and PRMV was high with the high volume spray (Table 4) (E). These contradictory results could be due to the greater contact of abscission chemicals in high spray volumes with the fruit stem. The coefficient of variation (CV) of deposition decreased with an increase of spray volume. Therefore, the higher volume spray (E) delivered a more uniform deposition than the lower volume spray (A) and the higher uniformity may have contributed to better loosening. As expected, the CMN-P depositions on the outside of the canopy were greater than depositions inside the canopy. Canopy height affected the FDF in the untreated control (F), but not in the treated. Uniform loosening (FDF) throughout the canopy would be preferable to increase the efficiency of mechanical removal of fruit. The percent pre-harvest drop (PDRP), clamp-pad location of shaker (20.5-24.8 cm) and tree trunk circumference (53.0-57.8 cm) were not significantly different.

Figure 1. Normalized dye deposition and CMN-P deposition on leaves and fruit (A) at 2 canopy heights and (B) at 2 penetration depths using Titan and FMC sprayers (February 5, 1999).

ments were both about 93% and were somewhat higher than that of the untreated control (88.0%), but not statistically different.

#### Study No. 2

Only minimal effects of spray volume and chemical rate on FDF and PRMV occurred in December 10 test (Table 3). Daily high temperatures were in the 70's°F (21°C) for the 3 days after spray, and dropped in the last 5 days prior to harvest into the 60's°F (16°C). Even though there was some visible evidence of abscission chemical activity in the form of fruit rind injury, the cool days prior to harvest were thought to reduce the fruit loosening effects of the chemical (Wilson et al., 1977). Increasing the CMN-P application rate reduced FDF, but the PRMV remained unaffected. The FDF in the lower canopy was lower than that in the upper canopy for all treatments and was unaffected by the abscission chemical.

Increasing the spray volume (the first objective) significantly affected the normalized dye depositions in the February 17 test (Fig.3-A). The low volume spray (A:560 L/ha (60 gpa)) achieved 1.7-1.9 times greater dye deposition than the high volume spray (E:5050 L/ha (540 gpa)), implicating a lower deposition efficiency or a higher amount of run-off at high spray volume. The dye depositions on the lower canopy

Table 3. Means and coefficients of variation (CV) in parentheses of fruit detachment force (FDF), percent fruit removal (PRMV) and yield of 'Hamlin' orange as affected by (a) spray volume and (b) CMN-P application rate (December 10, 1998 test in study No. 2).

(a) spray volume effect at CMN-P application rate of 140 g/ha				
Dependent variables	Treatment** [spray volume, L/ha]			
	A [470]	C [1400]	E [4210]	F [control]
FDF, N	90.8a* (19)	90.1a (21)	91.8a (18)	97.2a (19)
PRMV, %	87.9a (6)	82.1a (6)	85.7a (4)	83.4a (3)
Yield, kg	147.2b (14)	178.8ab (6)	195.4a (13)	167.4ab (16)

(b) CMN-P application rate effect at the spray volume of 1400 L/ha				
Dependent Variables	Treatment*** [CMN-P application rate, g/ha]			
	B [280]	C [140]	D [70]	F [control]
FDF, N	84.6b* (33)	90.1ab (21)	92.5ab (27)	97.2a (19)
PRMV, %	82.7a (9)	82.1a (6)	84.2a (7)	83.4a (10)
Yield, kg	180.2a (4)	178.8a (6)	185.3a (14)	167.4a (16)

\*Means within each row followed by different letters indicate significant difference using LSD at 5% level.

\*\*CMN-pyrazole was applied at the concentrations of 300, 100 and 33 mg/L for the treatments of A, C, and E, respectively.

\*\*\*CMN-pyrazole was applied at the concentrations of 200, 100 and 50 mg/L for the treatments of B, C, and D, respectively.

When the chemical application rate varied, the quantitative depositions of CMN-P were not directly proportional to the normalized dye deposition. Varying the chemical application rate in the second objective, normalized dye depositions did not differ from each other (Fig. 3-B). The similar dye depositions among the treatments indicated a consistent deposition efficiency or run-off possibility because the spray volumes remained constant regardless of chemical rate applied. The dye deposition on the lower and outside canopy was the highest for all three treatments.

Thus, CMN-P depositions increased with the increase of chemical application rate (Table 5) whereas the deposition efficiency remained unchanged. As deposition increased, PRMV increased and FDF decreased. The PRMV at the high chemical rate (B:505 g/ha (7.2 oz/a)) was better than at lower rates (C:253 g/ha (3.6 oz/a) or D:126 g/ha (1.8 oz/a)) and in the untreated control (F). The CMN-P deposition on the lower and outside of canopy was the highest in all three treatments, since the deposition efficiency was the highest. The coefficients of variation (CV) of deposition were similar for treatments B, C and D since the spray volume was held constant. Therefore, CMN-P application rate was not correlated with the dye deposition (FDEP1) or uniformity (CV). Higher concentrated sprays at the same spray volume rate, deposited more CMN-P on the fruit (FDEP2). Thus, more chemical resulted in better loosening of fruit (lower FDF), higher PRMV and PDRP. Chemical rate was the dominant factor in determining harvest efficacy at a constant spray volume. However, greater fruit rind injury and pre-harvest drop of fruit were observed at the higher rates of chemical.

The chemical depositions on the leaves (LDEP2) were strongly correlated with chemical depositions on the fruit (FDEP2) (Pearson corr. coef. = -0.793, prob. = 0.002) (Fig. 4).

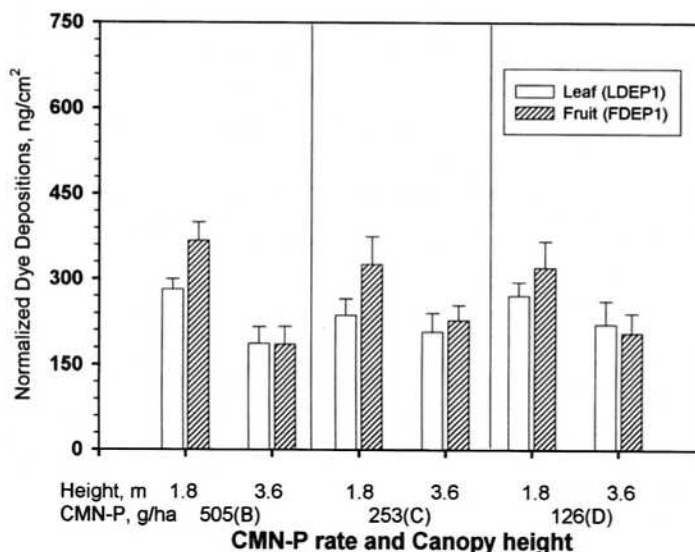
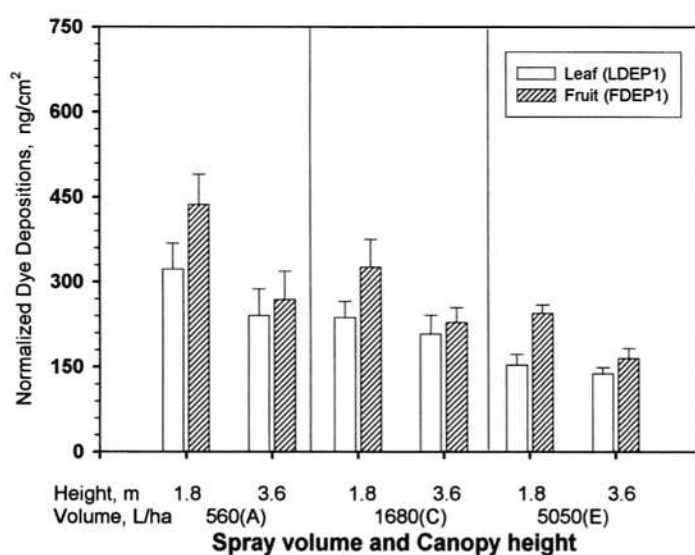


Figure 3. Normalized dye depositions on the leaves (LDEP1) and fruit (FDEP1) at different canopy heights for the effects of (A) spray volume and (B) CMN-P application rate (February 17, 1999).

Table 4. Means and coefficients of variation (CV) in parentheses of CMN-P depositions on leaves (LDEP2) and fruit (FDEP2), fruit detachment force (FDF), percent pre-harvest drop (PDRP) and the percent fruit removal (PRMV) as affected by spray volume rate at the CMN-P application rate of 253g/ha (the objective 1 of February 17 test in study No. 2).

Dependent variables	Treatment** [spray volume, L/ha]			
	A [560]	C [1680]	E [5050]	F [control]
LDEP2, $\mu\text{g}/\text{cm}^2$	0.144a* (48)	0.113a (38)	0.074b (30)	—
FDEP2, $\mu\text{g}/\text{cm}^2$	0.180a (47)	0.141ab (43)	0.104b (29)	—
FDF, N	69.4ab (39)	50.7b (67)	44.9b (54)	85.0a (29)
PDRP, %	0.34a (92)	0.77a (62)	0.49a (53)	0.35a (164)
PRMV, %	86.6b (4)	86.9b (5)	95.8a (3)	79.4c (10)

\*Means within each row followed by different letters indicate significant difference using LSD at 5% level.

\*\*CMN-pyrazole was applied at the concentrations of 450, 150 and 50 mg/L for the treatments of A, C, and E, respectively.

Table 5. Means and coefficients of variation (CV) in parentheses of CMN-P depositions on leaves (LDEP2) and fruit (FDEP2), fruit detachment force (FDF), percent pre-harvest drop (PDRP) and the percent fruit removal (PRMV) as affected by CMN-P application rate at the spray volume of 1680 L/ha (180 gpa) (the objective 2 of February 17 test in study No. 2).

Dependent Variables	Treatment** [CMN-P application rate, g/ha]			
	B [505]	C [253]	D [126]	F [control]
LDEP2, $\mu\text{g}/\text{cm}^2$	0.236a* (36)	0.113b (38)	0.063c (39)	—
FDEP2, $\mu\text{g}/\text{cm}^2$	0.282a (47)	0.141b (43)	0.067c (48)	—
FDF, N	28.5d (91)	50.7c (67)	67.2b (43)	85.0a (29)
PDRP, %	4.06a (108)	0.77ab (62)	0.34b (94)	0.35b (164)
PRMV, %	96.5a (2)	86.9b (5)	87.9b (4)	79.4b (10)

\*Means of each row followed by the same letters indicate insignificant difference using LSD at 5% level.

\*\*CMN-pyrazole was applied at the concentrations of 300, 150 and 75 mg/L for the treatments of B, C, and D, respectively.

more deposition on the fruit than on the leaves, and FDEP2 could probably be projected from the LDEP2. Thus, only leaf samples can be collected for ergonomic reasons in future deposition tests.

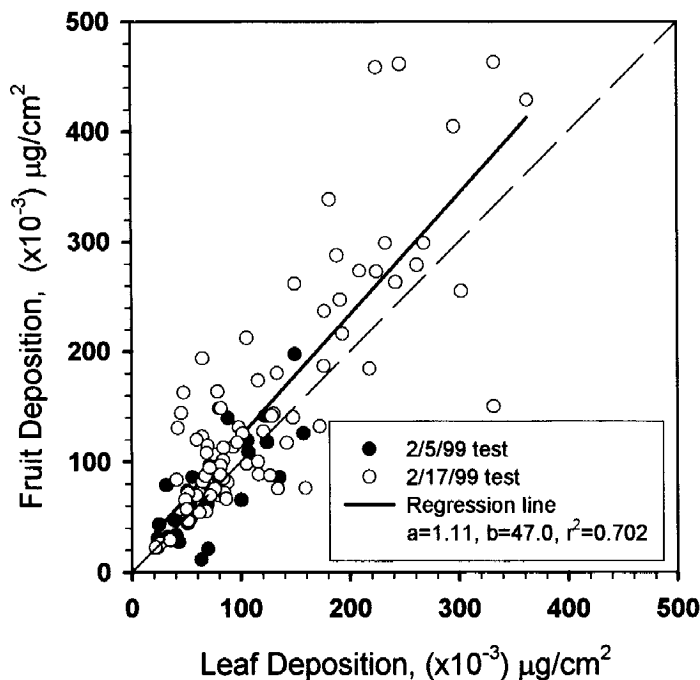


Figure 4. Linear correlation between CMN-P depositions on the leaves(LDEP2) and fruit (FDEP2).

The Titan tower sprayer gave higher deposition and better canopy penetration than the conventional FMC sprayer. Generally, deposition on the lower canopy was greater than that on the upper canopy, and deposition on the outside of the canopy was greater than that inside the canopy for the Titan sprayer.

Lower volume sprays delivered higher depositions than higher volume sprays due to greater deposition efficiencies. However, lower fruit detachment force and higher percent removal of fruit were observed with the high volume sprays, which may have allowed for greater contact ability and better uniformity (CV) of deposition.

CMN-P depositions increased with chemical application rate increase while the deposition efficiency remained unchanged. The effects of chemical rate dominated the results of mechanical harvesting efficacy. However, greater fruit rind burn and pre-harvest drop of fruit were observed at the higher rates of chemical application. The height in the canopy affected the natural FDF in the untreated control, but not in the spray treated trees. Therefore, the CMN-P application reduced the natural differences in FDF at various heights.

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