Spray Variable Effects on Abscission of Orange Fruit for Mechanical Harvesting

Y. M. Koo, M. Salyani, J. D. Whitney

Abstract. *An experimental abscission chemical, CMN-Pyrazole (CMN-P), was applied to 'Valencia' orange trees to investigate the effects of spray variables on fruit detachment force and mechanical harvesting efficiency of a trunk shaker. Spray variables included sprayer type, spray volume, ground speed, and CMN-P application rate. Harvesting efficacy was assessed in terms of fruit detachment force, pre-harvest drop of fruit, and percent fruit removal by the shaker. At comparable volume rates, CMN-P deposition was not significantly different for the Titan tower and AirFlow sprayers; however, harvesting efficacy was slightly better with the latter. Lower volume sprays resulted in higher deposition than higher volumes. However, more uniform deposition, lower fruit detachment force, and higher percent fruit removal were observed with higher volume sprays. Increasing the ground speed at constant sprayer output improved deposition efficiency, but more uniform spray distribution, better canopy penetration, and higher harvesting efficiencies were obtained at lower ground speeds.*

Keywords. *Abscission, Citrus, CMN-Pyrazole, Deposition, Mechanical harvest, Spray volume.*

Labor costs for citrus harvesting are a major expense in Florida (Muraro, 1997). Concerns about the availability of adequate harvesting labor at a reasonable cost have triggered the industry's interest in mechanical harvesting alternatives. Some mechanical harvesters have been studied since the early 1960s. Many different concepts of shakers, such as trunk shaker, limb shaker, foliage shaker, and air shaker, have been investigated (Whitney, 1995, 1999). Some abscission chemicals have been identified for enhancing mechanical harvesting efficiency by loosening fruit. An experimental abscission chemical, CMN-Pyrazole (Release®, Abbott Laboratories, Chicago, Illinois) has been proven effective, but was never registered (Hartmond et al., 1999; Whitney et al., 1999).

The efficiency of fruit removal by shaking is inversely related to fruit detachment force (FDF). Kender and Hartmond (1999) found fruit detachment force to be variable within citrus trees and generally lower in the lower canopy. An abscission chemical must be deposited on the fruit to obtain effective fruit loosening. Thus adequate coverage of an abscission material spray, especially in the upper canopy, is of importance to ensure uniform loosening.

Salyani and McCoy (1989) investigated the effect of spray volume on deposition using a tower sprayer. They concluded that mean deposition and variability of deposition (CV) increased as spray volume decreased. Hoffmann and Salyani (1996) studied the effects of application time and spray volume on deposition. Night applications gave higher deposition than daytime sprays as long as leaves were dry. Wet leaf surfaces (dew condensation) reduced the deposition, particularly at higher volume rates. The decrease in deposition for higher spray volume rates was due to the run-off from the target surface. Cunningham and Harden (1998) studied spray retention and run-off on citrus leaves. The percent retention of spray decreased when applied at rates above 2000 L/ha and slower sprayer speeds reduced the retention due to excessive airflow. Salyani (1999) defined deposition efficiency as deposition ($\mu g/cm^2$) per unit discharge during 1 cm of sprayer travel (mg/cm). He stated that deposition efficiency at high volume rates may be increased by increasing the number of nozzles and spraying at higher ground speeds. Applying abscission materials to 'Hamlin' orange trees, Koo et al. (1999) found higher volume sprays resulted in lower deposition due to greater run-off, but gave better efficacy in loosening fruit. Also, higher chemical rates gave better harvesting efficacy.

The objectives of this study were to: (1) investigate the effects of sprayer type and application variables on deposition of an abscission chemical; and (2) determine the relationship between the spray deposition and mechanical harvesting efficacy in 'Valencia' orange trees.

Materials and Methods

Two field experiments were conducted in a commercial grove, near Crewsville, Florida, on 23 April (Experiment 1) and 7 May 1999 (Experiment 2), during the 'Valencia'

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harvesting season. Spray treatments and an untreated control were replicated three times using a randomized complete block design. The 'Valencia' orange trees were on two-row-beds separated by ditches with alternate spacings of 3.0 and 4.6 m in the row, and row spacings of 6.7 and 7.8 m across the bed and ditch, respectively (fig. 1). Each plot consisted of four trees, 4.3 to 5.2 m in height.

Experiment 1

The objective of the experiment was to investigate the effects of sprayer type and spray volume on spray deposition and mechanical harvesting efficacy, using a constant CMN-P rate of 652 g a.i./ha. Details of the treatments and application variables are given in table 1a.

Two engine-driven tower sprayers (AirFlow 500 and Titan 1093) were used in the experiment. The AirFlow (Chemical Containers, Inc., Lake Wales, Florida) was an air-curtain sprayer similar to Curtec (BEI, Inc., South Haven, Michigan) and utilized four vertically stacked cross-flow fans and rotary atomizer units (one atomizer per fan) on each side. It was calibrated to deliver 230 and 940 L/ha at ground speeds of 4.8 and 2.0 km/h, respectively. The Titan (John Bean Sprayers, LaGrange, Georgia) was an air-blast sprayer, which was equipped with an axial-flow fan, an air tower attachment, and hydraulic nozzles. The sprayer had 34 nozzles/side, which were vertically spaced at about 15 cm. It was calibrated to deliver 940 and 4350 L/ha at ground speeds of 2.0 and 2.4 km/h, respectively. The inclination angles of the top two fans (AirFlow) and the tower head (Titan) were adjusted to direct the spray-laden air over the entire canopy height, as uniformly as possible.

Table 1. Spray treatments and application variables of the experiments

Treatment				CMN-P a.i.		Nozzle/Atomizer			
Group	Code	Volume (L/ha)	Speed (km/h)	Conc. (mg/L)	App. Rate (g/ha)	No./ Side	Type*	Flow (L/min)	Press (kPa)
(a) Experiment 1									
Titan	TH	4350	2.4	150	652	34	DC	63.3	1070
	TM	940	2.0	698	652	20	CJ	11.4	930
AirFlow	AM	940	2.0	698	652	4	RA	11.4	100
	AL	230	4.8	2790	652	4	RA	6.7	100
Control	CHK	0	0	0	0	0		0	0
(b) Experiment 2									
High-vol.	HS	6520	1.6	150	979	34	DC	63.3	1070
	HM	3260	3.2	150	489	34	DC	63.3	1070
	HF	2170	4.8	150	326	34	DC	63.3	1070
Low-vol.	LS	1960	1.6	498	979	34	CJ	19.1	880
	LM	980	3.2	498	489	34	CJ	19.1	880
	LF	660	4.8	498	326	34	CJ	19.1	880
Control	CHK	0	0	0	0	0		0	0

* Nozzles/Atomizers: DC = ceramic disc-core D4-25 (Spraying Systems Co., Wheaton, Illinois), CJ = ConeJet TXVK-6 (Spraying Systems Co., Wheaton, Illinois), and RA = rotary atomizer (BEI, Inc., South Haven, Michigan).

Experiment 2

The objective of the experiment was to investigate the effects of spray volume, sprayer ground speed, and CMN-P application rate on spray deposition and mechanical harvesting efficacy, using high- and low-volume nozzles at different ground speeds. The high- and low-volume rates (63.3 and 19.1 L/min per side) obtained with 34 D4-25 ceramic disc-core and TXVK-6 ConeJet nozzles (Spraying Systems Co., Wheaton, Illinois), respectively. Table 1b shows additional details of the applied treatments.

Sampling and Measurements

For both experiments, spray mixtures contained the abscission agent CMN-Pyrazole (CMN-P) (5-chloro-3-

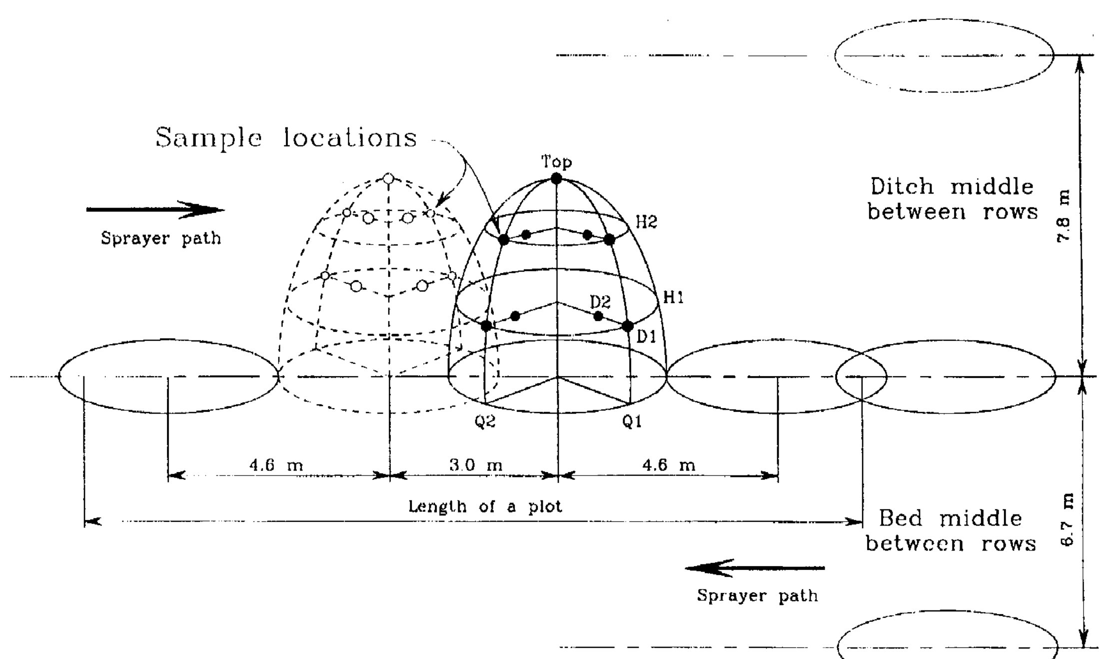


Figure 1–Schematic view of the two-row-bed test plot and sampling locations at leading (Q1) and trailing (Q2) quadrants (w.r.t. sprayer paths) along the bed (□) and ditch (o) row middles.

methyl-4-nitro-1H-pyrazole: 17.18% a.i. (w/w), Abbott Lab., Chicago, Illinois), Kinetic® surfactant at 0.1% (v/v) (Setre Chemical Co., Memphis, Tennessee), and Pyranine 10G fluorescent dye tracer (Keystone Aniline Inc., Chicago, Illinois). The mixtures were sprayed onto orange trees and sampling for dye deposition was completed within 1.5 h after spraying. In preliminary tests, the dye was found to have less than 10% degradation after 1 h of exposure to direct sunlight.

Two center trees of each plot were used for experimental measurements (fig. 1). Spray deposition was sampled along the bed and ditch middles at leading (Q1) and trailing (Q2) quadrants (with respect to sprayer travel paths) at nine canopy locations per tree. At each sample location, three to five leaves were collected at two canopy heights (H1 = 1.8 m, H2 = 3.6 m), two canopy depths (D1 = outside, D2 = about 60 cm inside), and from the top center (TOP) of the tree. The samples were stored in sealable plastic bags and later analyzed by fluorometry. Four to five days post-treatment, harvesting parameters were quantified on the same center trees of each plot. In the Experiment 2, deposition samples were collected from the bed middle side only and harvest results were totaled for the two middle trees.

Spray Deposition. The leaf samples were washed with 100 mL of deionized water and the sample fluorescence was measured by a fluorometer (Model 111, Sequoia-Turner Corp., Mountain View, California). The dye was easily washable from the leaf surface and preliminary tests had shown a recovery rate of better than 99%. Leaf area was measured using an area meter system (Delta-T Devices Ltd., Cambridge, U.K.). Dye deposition per unit area ($\eta g/cm^2$) was normalized to a nominal dye application rate of 494 g/ha to compare the treatments with different dye concentrations.

Deposition efficiency (DEP), a relative index of spray retention on the canopy [dye deposition ($\eta g/cm^2$) per unit application of dye in a unit land area ($\mu g/cm^2$)], was used as a criterion to compare different treatments. The amount of CMN-P deposited on leaves (LDEP) was calculated from the dye deposition. The CMN-P deposition on fruit, related to the mechanical harvesting efficacy could be projected from the leaf deposition (Koo et al., 1999).

Harvesting Parameters. Prior to harvest, the number of fruit on the ground was counted to determine preharvest drop (PDRP). Fruit detachment force (FDF) was measured using a pull force gauge (Model FDV-50, Wagner Instrument, Greenwich, Connecticut). The measurements were made on five fruit at two canopy heights of 1.5 to 2.1 m and 3.6 to 4.2 m. On the same day, each tree was shaken for 5 s at 6 Hz frequency and 5 cm displacement, using a trunk shaker (Fruit Harvester International Inc., Alva, Florida). The mechanically removed fruit and the fruit remaining on the tree (picked manually) were weighed separately to determine harvesting efficiency as percent removal (PRMV, included PDRP) of the total fruit yield. The heights of the shaker clamp-pad on the trunk and the tree trunk circumference also were recorded since PRMV has been found to be related to shaker clamp-pad height and inversely related to tree trunk circumference (Whitney et al., 1988).

Data Analyses. Data were analyzed using the PROC MIXED model of SAS with LSMEAN/PDIFF options (Littell, 1999). Variability of deposition was expressed as the coefficient of variation (CV), and the means were separated by LSD at the 5% significance level (SAS 1990).

Results and Discussion

Since the height of the top center sampling location (TOP) was variable, deposition data corresponding to that location were only used to verify the adjustments of the top spray units of both sprayers (data excluded from the analysis of main effects). The effects of sampling direction and tree number were not significant in spray deposition; therefore, the observations from each of the two sampled trees of each plot were considered a replication and the data were analyzed as six replications. However, the mechanical harvesting data of the Experiment 2 were analyzed as three replications because data of the two trees in each plot were not acquired separately. Generally, the height of shaker clamp-pad and tree trunk circumference were not significantly different between treatments, in either experiment, and therefore should not have contributed to differences in percent fruit removal (PRMV).

Experiment 1

AirFlow versus Titan Sprayer (AM vs TM). CMN-P depositions (LDEP) of the two sprayers (at 940 L/ha) were not significantly different (table 2). However, the lower CV of deposition for the AirFlow sprayer indicated more uniform deposition, compared to that for the Titan sprayer. More deposition was measured in the upper canopy with the AirFlow sprayer, while the Titan sprayer deposited more in the lower canopy (fig. 2a). This was likely due to the differences in air delivery patterns. Deposition on the outside (OUT) of the canopy was 1.5 times higher than that of the inside (IN) with the Titan sprayer, but only 1.1 times greater with the AirFlow sprayer (fig. 2a). Thus, the latter delivered more uniform deposition and better canopy penetration than the Titan sprayer. The sampling quadrant

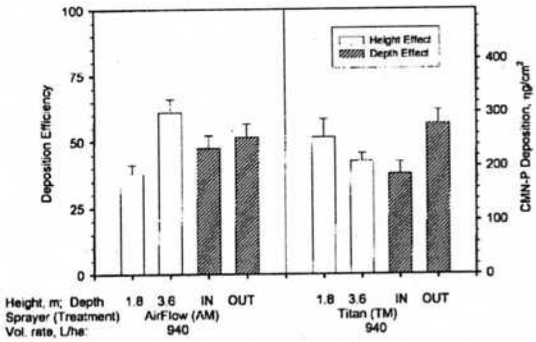
Table 2. Deposition and harvesting results in Experiment 1*

Treat-ment Code	Volume (L/ha)	LDEP (hg/cm^2)	DEP (%)	FDF (N)	PDRP (%)	PRMV (%)
(a) AirFlow Sprayer						
AL	230	293 a†	44.9a	101.3ab	2.2b	75.2b
		(73)‡	(73)	(37)	(20)	(14)
AM	940	322a	49.4a	61.6b	6.9a	92.0a
		(49)	(49)	(56)	(24)	(9)
CHK	0	-	-	102.5a	1.4b	84.3ab
				(37)	(7)	(9)
(b) Titan Sprayer						
TM	940	306a	47.0a	82.3ab	4.9b	87.6b
		(55)	(55)	(58)	(12)	(6)
TH	4350	162b	24.8b	42.1b	9.6a	97.4a
		(25)	(25)	(106)	(9)	(2)
CHK	0	-	-	102.5a	1.4c	84.3b
				(37)	(7)	(9)

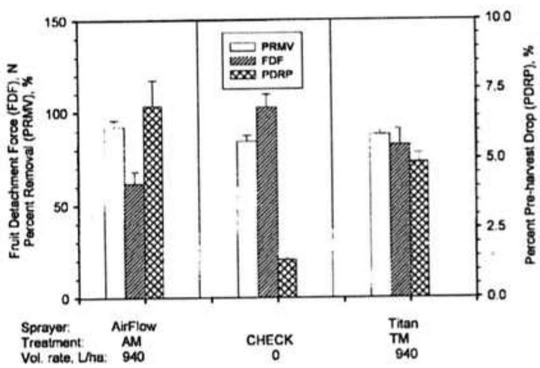
* Variable Legend: LDEP = CMN-P deposition at a constant application rate of 652 g/ha, DEP = deposition efficiency, FDF = fruit detachment force, PDRP = percent pre-harvest fruit drop, and PRMV = percent fruit removal.

† Means followed by the same letter (in a column) indicate insignificant difference using LSD at 5% level.

‡ Coefficient of variation (CV) of the means.

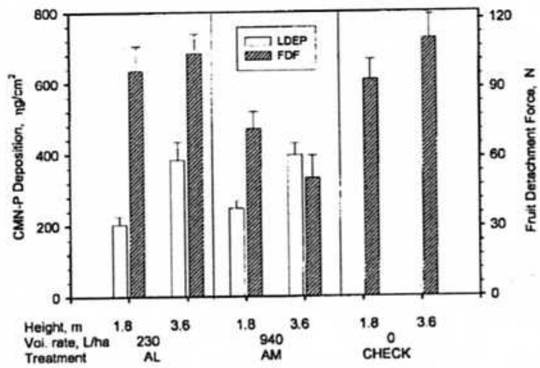


(a) Depositions at two canopy heights and depths

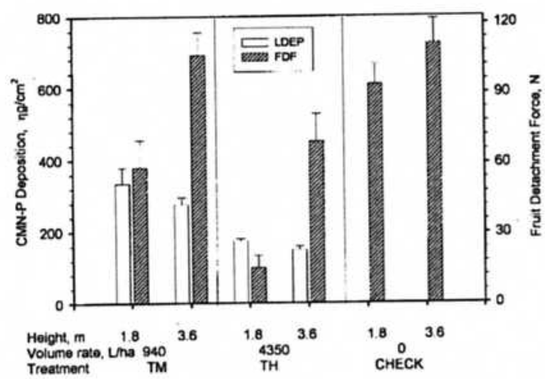


(b) Harvest efficacy

Figure 2–Deposition (a) and harvesting (b) results of Experiment 1.



(a) AirFlow 500 sprayer



(b) Titan 1093 sprayer

Figure 3–CMN-P deposition and fruit detachment force for the AirFlow (a) and Titan (b) applications in Experiment 1.

(leading vs trailing) did not affect the deposition (data not shown).

Overall FDF and PRMV were not significantly different between the treatments. However, FDF was somewhat lower and PRMV was higher for the AirFlow sprayer (AM), compared with those of the Titan sprayer (TM) and control (CHECK) treatment (fig. 2b). The percent pre-harvest drop (PDRP) for treatments AM and TM were higher than that of the control trees.

The deposition along the canopy height influenced the fruit detachment forces (FDF), which decreased with an increase of CMN-P deposition (fig. 3). The lower deposition of Titan sprayer at the upper canopy resulted in higher FDF at that level. While the higher deposition of the AirFlow sprayer in the upper canopy resulted in lower FDF, even with the naturally higher FDF in the upper canopy of the control treatment.

Spray Volume Effect with AirFlow Sprayer. CMN-P deposition (LDEP) was not significantly different between the two volumes (AL = 230 and AM = 940 L/ha) of the AirFlow sprayer (table 2a). Deposition efficiencies (DEP) of both treatments were not significantly different, but higher volume showed more uniform deposition (lower CV). Deposition in the upper canopy (H2) was 1.6 to 1.9 times greater than that in the lower canopy (H1) (fig. 3a). The higher amount of deposition in the upper canopy lowered FDF at the higher volume (AM), but resulted in minimal fruit loosening at the lower spray volume (AL). Overall, FDF was lower, and PDRP and PRMV were higher at the higher volume (940 L/ha) compared to those of the lower volume (230 L/ha) and unsprayed CHECK (table 2a).

Spray Volume Effect with Titan Sprayer. Spray volume of 4350 L/ha (TH) resulted in significantly lower LDEP than the spray volume of 940 L/ha (TM) (table 2b). DEP of higher spray volume indicated 45% less retention, compared to the lower spray volume. The effect of sampling height was not statistically significant on deposition for the Titan sprayer, but deposition on the lower canopy was numerically higher (fig. 3b). Deposition on the trailing quadrant (Q2) was greater than that on the leading quadrant (Q1) for the lower spray volume, but was not significantly different for the higher spray volume (data not shown).

Despite the low LDEP with high spray volume, FDF was lower and PDRP and PRMV were higher compared to the lower volume sprays and the control treatment (table 2b). The lower CV of deposition for high spray volume indicated more uniform deposition that might contribute to a more uniform loosening, compared to that of the lower volume spray.

Discussion on Experiment 1. Overall, the harvesting efficacy at low spray volume was minimal, regardless of the applied CMN-P chemical dosage. Deposition efficiency significantly decreased or run-off increased with an increase of spray volume above 940 L/ha. At the spray volume of 4350 L/ha, CMN-P deposition was as low as 162 ηg/cm^2; however, the percent fruit removal was the highest (97.4%). This contradictory result might be attributed to prolonged wetness of the fruit at higher volumes and greater contact of abscission chemical with the fruit stem. The AirFlow sprayer gave more favorable (more uniform) deposition and better efficacy compared with the Titan sprayer at a common spray volume rate of 940 L/ha. Fine spray droplets generated by the rotary atomizers and less turbulent air of the cross-flow fans of the AirFlow sprayer might have improved deposition. In addition, more deposition on the upper canopy with the AirFlow sprayer might have influenced uniform loosening of fruit throughout the upper canopy, where fruit detachment force is naturally higher.

EXPERIMENT 2

High versus Low Flow Rate Groups. Overall CMN-P deposition (LDEP), its CV, and deposition efficiency (DEP) at the high nozzle flow rates (H = 63.3 L/min) were lower than those at low flow rate group (L = 19.1 L/min) (table 3). Deposition on the outside canopy was significantly higher than on the inside for the low flow rate, but not significantly different for the high flow rate, indicating more uniform deposition (data not shown). Deposition on the trailing quadrant (Q2) was higher than that on the leading quadrant (Q1) for the low flow rate, but not for the high flow rate group. The higher LDEP in the lower canopy resulted in lower fruit detachment force (FDF), compared to that in the upper canopy (fig. 4). The LDEP of the high flow rate group (H) was lower due to lower DEP. However, the FDF was lower and PRMV was higher, compared with those of the low flow rate group (L) and unsprayed control (table 3). Again, the higher volume sprays provided better uniformity (lower CV) of deposition that might have contributed to more uniform loosening. Preharvest fruit drop (PDRP) was not significantly different between the two flow rate groups.

Ground Speed Effect at High Flow Rate. Since sprayer output was constant, sprayer ground speed was

Table 3. Deposition and harvesting results in Experiment 2*

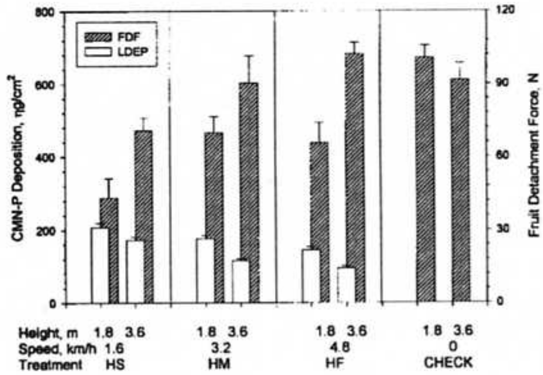
Treat-ments†	LDEP (ηg/cm^2)	DEP (%)	FDF (N)	PDRP (%)	PRMV (%)
High (H)	115 b‡ (37)§	28.6b (43)	73.7b (47)	4.6a (33)	90.7a (7)
Low (L)	228a (67)	39.7a (56)	87.0ab (48)	3.1a (41)	87.6a (4)
Control (CHECK)	-	-	96.2a (25)	-	86.6a (9)

* Variable Legend: LDEP = CMN-P deposition, DEP = deposition efficiency, FDF = fruit detachment force, PDRP = percent pre-harvest fruit drop, and PRMV = percent fruit removal.

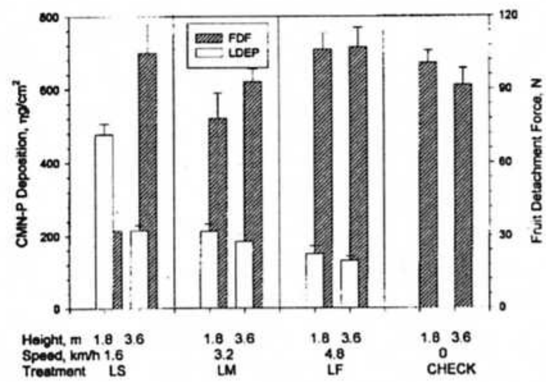
† Treatments 'H' and 'L' indicate flow rates of 63.3 and 19.1 L/min per side, respectively.

‡ Means followed by the same letter (in a column) indicate insignificant difference using LSD at 5% level.

§ Coefficient of variation (CV) of the means.



(a) High nozzle flow rate



(b) Low nozzle flow rate

Figure 4–CMN-P deposition and fruit detachment force for high- (a) and low-volume (b) nozzle flow rates in Experiment 2.

inversely related to spray volume and chemical application rates. With increasing spray volume, CMN-P dosage increased accordingly, but deposition efficiency (DEP) decreased (fig. 5). Variability of deposition (CV) decreased with decreasing ground speed, possibly due to increase of spray volume and runoff from leaf surface. Thus, the higher spray volume improved canopy penetration and provided more uniform deposition on tree quadrants.

Deposition on the upper canopy was lower, which resulted in higher FDF compared to the lower canopy (fig. 4a). FDF decreased and PRMV increased with decreasing ground speed (fig. 5). FDF at the highest rate (HS), achieved at the slowest ground speed, was significantly lower than those of the other treatments, whereas PRMV at lower ground speed was significantly higher. Preharvest fruit drop (PDRP) was not affected by sprayer ground speed (fig. 5).

Ground Speed Effect at Low Flow Rate. LDEP increased with a decrease in ground speed and the associated increases of spray volume and chemical application rates (fig. 6). LDEP was predominantly influenced by the increase of chemical application rate, as discussed in the previous section. There was a trend of decreasing DEP and CV with increasing spray volume, but

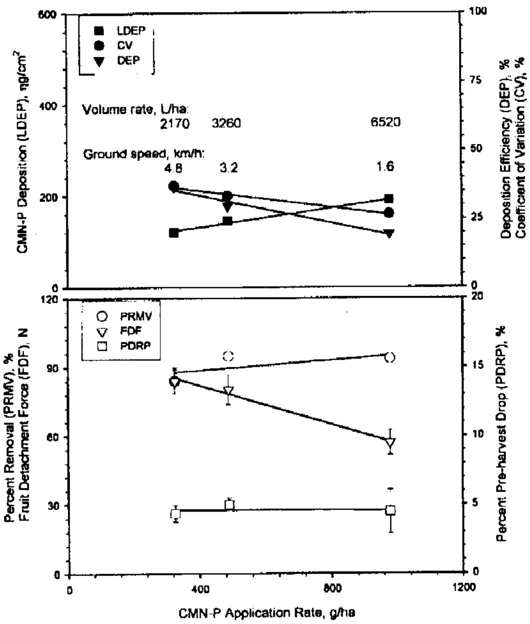


Figure 5–Deposition and harvest efficacy results for high flow rate applications in Experiment 2.

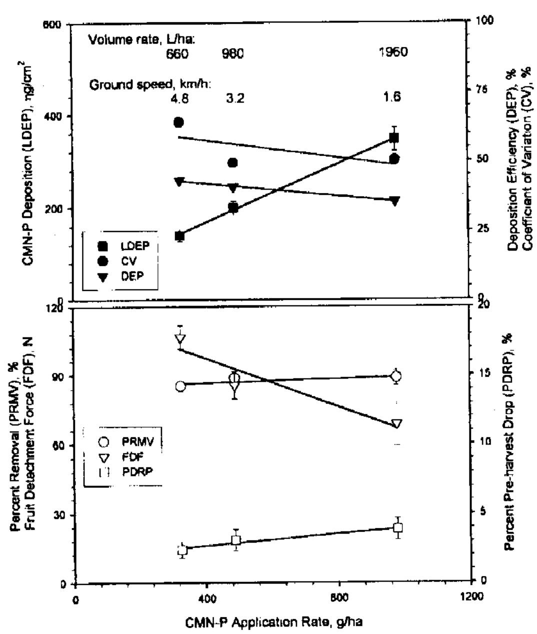


Figure 6–Deposition and harvest efficacy results for low flow rate applications in Experiment 2.

the differences were not significant. Deposition on the outside canopy was significantly higher than on the inside canopy, and deposition on the leading quadrant (Q1) was significantly lower than that on the trailing quadrant (Q2) (data not shown). These differences in spatial deposition level were greater at higher ground speeds and lower volume rates. Thus, the nonuniformity of deposition was more apparent with decreasing spray volume rates.

The higher LDEP in the lower canopy resulted in lower FDF, as expected from the deposition distribution (fig. 4b). FDF decreased and PRMV increased with a decrease of ground speed, increases of spray volume and chemical application rate (fig. 6). The FDF at the highest chemical rate was significantly different from other treatments. However, PRMV and PDRP were not statistically different. The overall effects of abscission spray on mechanical harvest efficacy were minimal in the lower flow rate group.

Overall, minimal efficacy was observed in the low spray flow rate group due to lower spray volumes, resulting in high variability (CV) of deposition. Ground speeds below 3.2 km/h at the high flow rate group delivered enough spray volume and abscission material to loosen fruit for effective harvest. Deposition efficiency increased with ground speed and to some extent offset the decrease in CMN-P application rate at higher speeds (fig. 6).

Discussion on Experiment 2. Overall, deposition efficiencies of the 2 treatments with comparable volume rates (table 1b, HF and LS) were not significantly different (figs. 5 and 6). Both treatments also showed similar canopy penetration (data not shown). However, the one with lower nozzle flow rate (LS) indicated relatively non-uniform deposition compared to the one at higher flow rate (HF). A faster application at high flow rate might deliver more favorable depositions to the upper canopy and the tree quadrants. Despite the similarities in deposition, the slower treatment (LS), with 3 times more CMN-P application rate than the faster treatment (HF), showed better efficacy results than the latter.

Conclusions

1. At comparable volume rates, overall CMN-P deposition was not significantly different for The Titan 1093 and AirFlow 500 tower sprayers; however, harvesting efficacy was slightly better with the latter.
2. The lower volume sprays resulted in higher deposition than higher volumes; however, more uniform deposition, lower fruit detachment force, and higher percent fruit removal were observed with higher volume sprays.
3. Increasing the ground speed at constant sprayer output improved deposition efficiency, but more uniform spray distribution, better canopy penetration, and higher harvesting efficiencies were obtained at lower ground speeds.

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