Effect of Application Techniques on Abscission Chemical Deposition and Mechanical Harvesting of 'Valencia' Oranges

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ADDITIONAL INDEX WORDS. airflow, nozzle, 5-chloro-3-methyl-4-nitro-1H-pyrazole, Pyranine, fruit detachment force, trunk shaker, sprayer

SUMMARY. Field experiments were conducted to investigate the effect of sprayer type, airflow rate, and nozzle output on deposition of active ingredient and mechanical harvesting of 'Valencia' orange (Citrus sinensis). Fruit detachment force (FDF) and percentage of fruit removal (PFR) by trunk shaker were used as mechanical harvesting parameters. A PowerBlast sprayer discharging radially and a Titan sprayer discharging over the entire canopy were used. The spray mixture contained an abscission chemical (CMN-pyrazole), a surfactant (Kinetic) and a fluorescent tracer (Pyranine-10G). Deposition was determined at three different heights outside and inside of the canopy. With the PowerBlast, higher airflow and lower nozzle output reduced deposition of the active ingredient. The mean FDF of sprayed treatments was less than that of the non-sprayed control but the difference among the four spray treatments was not significant. The lower airflow rate with lower nozzle output had higher PFR than that of the control. With the Titan sprayer, the mean deposition at lower airflow was similar to or higher than the higher airflow. At higher airflow, the lower nozzle output gave higher mean deposition. The Titan sprayer treatments resulted in less FDF than the control. At both airflow rates, the FDF was less at lower nozzle output than at higher nozzle output. The PFR of these treatments were not different from that of control.

Abscission chemicals are important ingredients to improve the efficiency of mechanical harvesting of citrus (*Citrus* spp.) (Salyani et al., 1999). These chemicals have shown to reduce fruit detachment force (FDF) and enhance fruit removal efficiency of trunk shakers by 17 to 26 percentage points (Hedden et al., 1988). The full potential of any such chemical cannot be realized unless it is applied effectively. Generally, a spray application is considered satisfactory if it is deposited uniformly within the tree canopy. Specifically, the abscission chemical needs to be applied to the target fruit. The efficacy of the abscission chemicals depends on the dose transfer and application parameters (Kender et al., 1999). Kender and Hartmond (1999) have reported that fruit detachment force is generally higher in the upper canopy of citrus trees. Thus, adequate coverage of the tree canopy especially at the upper part of the tree is of prime importance.

The deposition of spray materials on tree leaves has been studied in response to droplet size (Salyani, 1988), spray volume (Richardson et al., 2000; Salyani et al., 1988), and travel speed (Randall, 1971; Salyani and Whitney, 1990; Whitney et al., 1989). Koo et al. (1999, 2000) investigated the effects of spray variables on fruit detachment force and mechanical harvesting efficiency of a trunk shaker. In those studies of deposition from two sprayers they found that the sprayer type did not affect overall deposition but affected uniformity. The difference in uniformity was attributed to different types of air delivery systems. The authors also found that the deposition of low volume application was higher than deposition of the more dilute high volume application. However, the latter gave lower fruit detachment force and higher fruit removal rate. High volume application produced more uniform deposition than that by low volume application. BenSalem et al. (2001) also reported that the sprayer type did not affect the deposition. Spray release height affected spray deposition along canopy height but the deposition at different heights was not proportional to delivery rates directed to respective heights. Nighttime application resulted in higher deposition at low volume, but high volume had stronger effect on fruit detachment force and fruit removal than the low volume spray.

The focus of this study was to determine how a spray delivery system affects spray deposition and harvesting efficiency of the 'Valencia' orange. The response variables were the active ingredient deposition, fruit detachment force, and the percent fruit removal by the trunk shaker.

Materials and methods

Two experiments were conducted in a commercial 'Valencia' orange (*Citrus sinensis*) grove near Crewsville, Fla. Both experiments took place during the 2001 crop season. A PowerBlast sprayer (Rears Spraying Systems, Eugene, Ore.) was used in experiment 1 on 27 Apr. and Titan 1093 sprayer (John Bean Sprayers, Hogansville, Ga.) was used in experiment 2 on 4 May. In these experiments, spray treatments including a non-sprayed control were replicated four times using a randomized complete block design. Table 1 describes eight different treatments used over the two experiments. Each plot consisted of four trees in a row. The two middle trees were used for experimental measurements while the two outer trees were treated as buffers. The trees were on two-row beds separated by ditches (water furrows). The trees were spaced alternately at 3.0 and 4.6 m (10 and 15 ft) in a row and at 6.7 and 7.9 m (22 and 26 ft), across the bed and ditch, respectively.

The PowerBlast is a tractor power-take-off-driven standard air-blast sprayer and the Titan 1093 is an engine-driven tower sprayer. Both used axial-flow fan and hydraulic nozzles. The two sprayers had different air and spray delivery systems. The PowerBlast sprayer discharged radially towards the canopy whereas the

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Table 1. Definition of treatments and application parameters for two experiments to investigate the effect of sprayer type, airflow rate, and nozzle output on deposition of active ingredient and mechanical harvesting of 'Valencia' orange in Crewsville, Fla.

Spray treatment[z]	Sprayer	Airflow rate ($m^3 \cdot s^{-1}$)[y]	Nozzle type	Nozzle flow rate ($mL \cdot s^{-1}$)[x]	Operating pressure (kPa)[w]	Ground speed ($km \cdot h^{-1}$)[v]
Expt. 1: PowerBlast sprayer						
PB4/18-BL	PowerBlast	11.4	Albuz Blue	63.6	1034.2	4.8
PB4/18-RH	PowerBlast	11.4	Albuz Red	42.3	1641.0	3.2
PB9/32-BL	PowerBlast	16.0	Albuz Blue	63.6	1034.2	4.8
PB9/32-RH	PowerBlast	16.0	Albuz Red	42.3	1641.0	3.2
Expt. 2: Titan sprayer						
T16-CS	Titan	28.0	SS TXVK-6	8.7	641.2	1.9
T16-DF	Titan	28.0	SS D4-25	22.6	599.8	4.8
T22-CS	Titan	37.0	SS TXVK-6	8.7	641.2	1.9
T22-DF	Titan	37.0	SS D4-25	22.6	599.8	4.8

[z]PB 4/18 and PB 9/32 = PowerBlast four-blade 18° fan and nine-blade 32° fan, respectively; BL = Albuz blue nozzle for higher nozzle output; RH = Albuz red nozzle for lower nozzle output; T16 and T22 = Titan operating at 1600 and 2225 rpm, respectively; CS = Conejet nozzle for lower nozzle output; DF = disc-core nozzle for higher nozzle output.

[y]$1.0\ m^3 \cdot s^{-1} = 35.32\ ft^3/s$.

[x]$1.0\ mL \cdot s^{-1} = 0.016$ gal/min.

[w]1.0 kPa = 0.15 lb/inch².

[v]$1.0\ km \cdot h^{-1} = 0.62$ miles/h.

Titan sprayer discharged almost horizontally over entire canopy height (Fig. 1). Volume application rate was kept constant at 1561.5 $L \cdot ha^{-1}$ (167 gal/acre) for all treatments in both experiments.

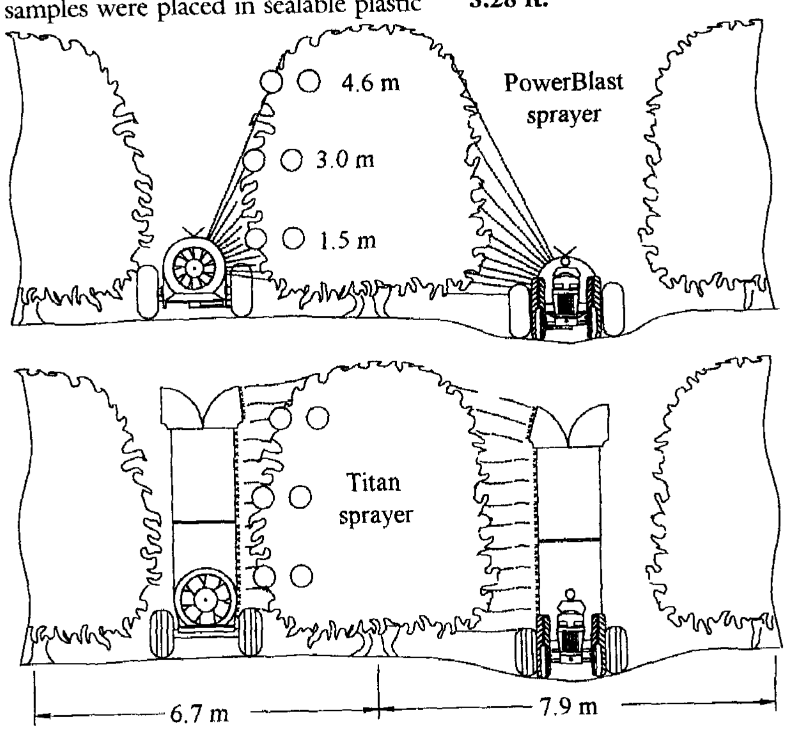
Airflow rate of the PowerBlast sprayer was changed by using either a four-blade 18° fan [PB4/18 (low airflow)] or a nine-blade 32° fan [PB9/32 (high airflow)]. The former uses 66.6% less engine power than the latter. Airflow rate of the Titan sprayer was changed by fan speed. The sprayer was operated either at 1600 rpm [T16 (low airflow)] or at 2225 rpm [T22 (high airflow)]. As energy demand of the sprayer fan increases (or decreases) by cube of the fan speed, the 1600 rpm require 37.2% of the engine power at 2225 rpm (62.8% energy saving). The nozzle size, pump speed, and ground speed were changed to maintain the volume application rate constant.

The PowerBlast sprayer was used with Albuz (Ceramiques Techniques Desmarquest, Evreux, France) cone nozzles: blue at 1034.2 kPa [BL (high output)] and red at 1641.0 kPa [RH (low output)] [150 and 238 lb/inch² (psi), respectively]. The Titan sprayer was used with Conejet TXVK-6 nozzle (Spraying Systems Co. Wheaton, Ill.) at 641.2 kPa [CS (low output)] and ceramic disc-core D4-25 nozzle (Spraying Systems Co.) at 599.8 kPa [DF (high output)] (93 and 87 psi, respectively).

The spray mixture contained abscission chemical CMN-pyrazole (CMN-P) [Release, 17.18% a.i. (wt/wt); Abbott Laboratories, Chicago, Ill.] at 674 $mg \cdot L^{-1}$ (ppm), surfactant (Kinetic; Helena Chemical Co., Memphis, Tenn.) at 0.1% vol/vol, and fluorescent tracer, Pyranine-10G (Keystone Aniline Inc., Chicago, Ill.) at 300 $mg \cdot L^{-1}$. The trees were sprayed on both sides (Fig. 1).

After spraying and allowing leaves to dry, leaf samples were collected from the leading and trailing quadrants of the two middle trees at 1.5, 3.0, and 4.6 m (5, 10, and 15 ft) heights from both the outside and inside [a depth of 0.61 to 0.76 m (2.0 to 2.5 ft) inside the outer surface] of the tree canopy. The leaf samples were placed in sealable plastic bags and stored in a cooler and then in a refrigerator at 4 °C (39.2 °F). The samples were washed with de-ionized water. The fluorescent tracer deposition on leaves was determined by the analysis of wash solutions and the leaf area measurements. Tracer concentration in the wash solution was quantified using a fluorometer (model 111; Sequoia-Turner Corp., Mountain View, Calif.) and leaf area was measured with an area meter (Delta-T Devices Ltd., Cam-

Fig. 1. Spray application with PowerBlast (top) and Titan (bottom) sprayers and sampling locations for deposition measurement; 1.0 m = 3.28 ft.



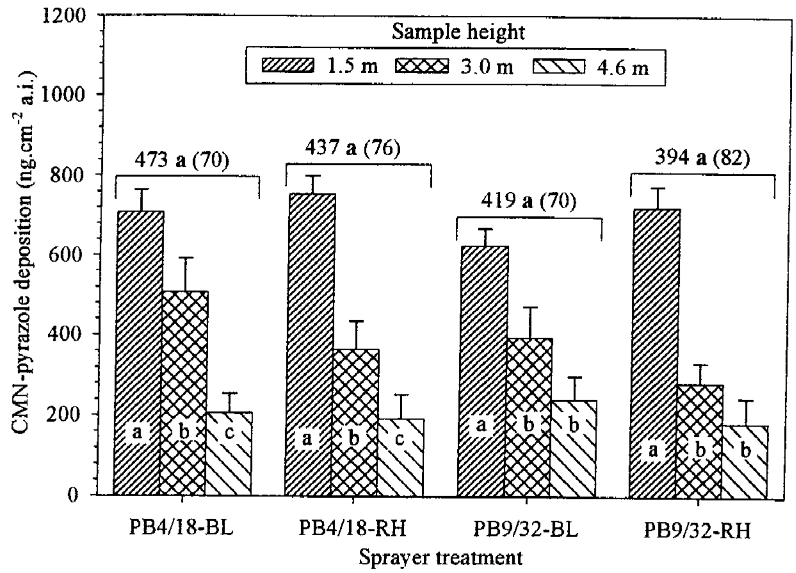


Fig. 2. Comparison of deposition at three heights from each PowerBlast treatment; boldface and regular letters separate means between and within treatments, respectively; numbers in parentheses are respective coefficients of variation; PB 4/18 and PB 9/32 = PowerBlast four-blade 18° fan and nine-blade 32° fan, respectively; BL = Albuz blue nozzle for higher output; RH = Albuz red nozzle for lower output; 1.0 m = 3.28 ft, 1 ng·cm^{-2} = 2.3 × 10^{-10} oz/inch^2.

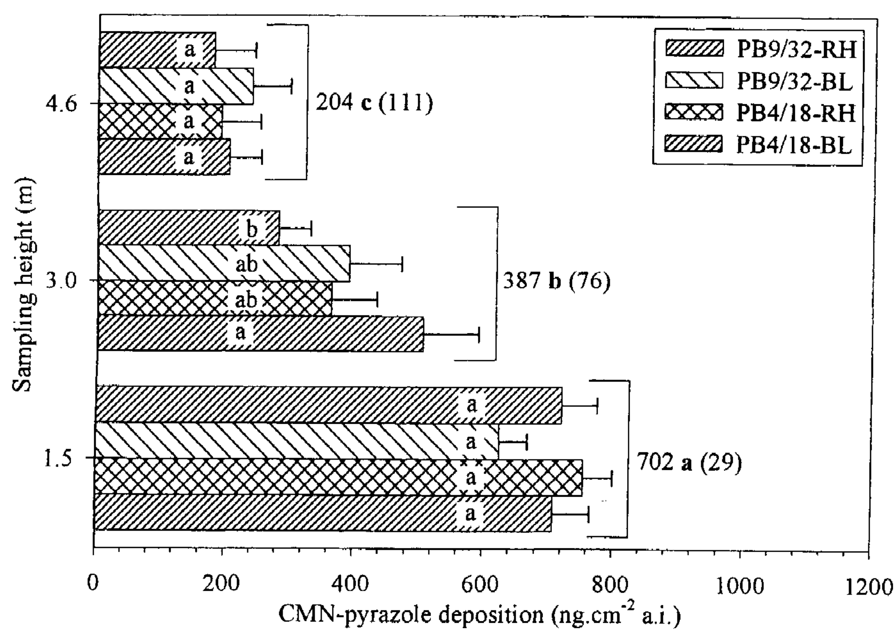


Fig. 3. Comparison of deposition from PowerBlast treatments at each height; boldface and regular letters separate means between and within treatments, respectively; numbers in parentheses are respective coefficients of variation; PB 4/18 and PB 9/32 = PowerBlast four-blade 18° fan and nine-blade 32° fan, respectively; BL = Albuz blue nozzle for higher output; RH = Albuz red nozzle for lower output; 1.0 m = 3.28 ft, 1 ng·cm^{-2} = 2.3 × 10^{-10} oz/inch^2.

bridge, UK). The CMN-P deposition was considered as proportional to the tracer deposition and was calculated from the latter.

Four to five days after spraying, fruit detachment force was measured with a pull force gauge (model FDV-50; Wagner Instrument, Greenwich, Conn.) for randomly selected oranges from the two middle trees at 1.5 m and 4.6 m heights (five oranges at each height). The abscission induced fruit drop was counted. The trees were shaken with a trunk shaker (Orchard Rite, Yakima, Wash.) for 5 s at 7 to 8 Hz and 5 cm (2.0 inch) displacement. After shaking, the fruit was collected and weighed. The fruits remaining on the trees were picked manually an weighed separately. The percent frui removal was calculated from these frac tions.

The data collected were analyze by the mixed model procedure (PRO MIXED) and means were compare using PDIFF option of LSMEAN statement (Littell et al., 1996). Th means were separated by the t-test a the 5% level of significance. Variabilit of the data was expressed by standar error and coefficient of variation. Rela tionship between spray deposition, frui detachment force and fruit remova were determined by CORR procedur in SAS (SAS Institute, 1990).

Results and discussion

Experiment 1: PowerBlast Sprayer

DEPOSITION. The airflow rate did not significantly affect the CMN-P deposition, although the lower airflow at both volume rates resulted in numerically higher mean deposition (Fig. 2). The nozzle output also did not affect the deposition. Deposition for all treatments was higher and less variable at 1.5 m than at other heights. It decreased with increase in height and became more variable. The overall mean deposition decreased significantly with increase in height (Fig. 3). At three heights, the lower airflow generally resulted in similar deposition to the higher airflow. There was only a significant difference in deposition between two treatments [PB4/18-BL and PB9/32-RH (Table 1)] at 3.0 m height but not at the other heights (Fig. 3).

On the outside of canopy, mean deposition was numerically higher at lower airflow than at higher airflow (Fig. 4) but the difference was significant only between PB4/18-BL and PB9/32-RH. The variation in deposition between different heights on the outer canopy was less at higher airflow than at the lower airflow. From all treatments, the deposition outside was lower at 4.6 m level than at the other levels. The higher nozzle output (BL) gave numerically higher deposition outside compared to lower nozzle output (RH). Overall, there was more deposition on the outside canopy than on the inside. Inside the tree canopy, there was no significant difference in mean deposition between the treatments. For higher nozzle output, the inside deposition was higher at 1.5 m

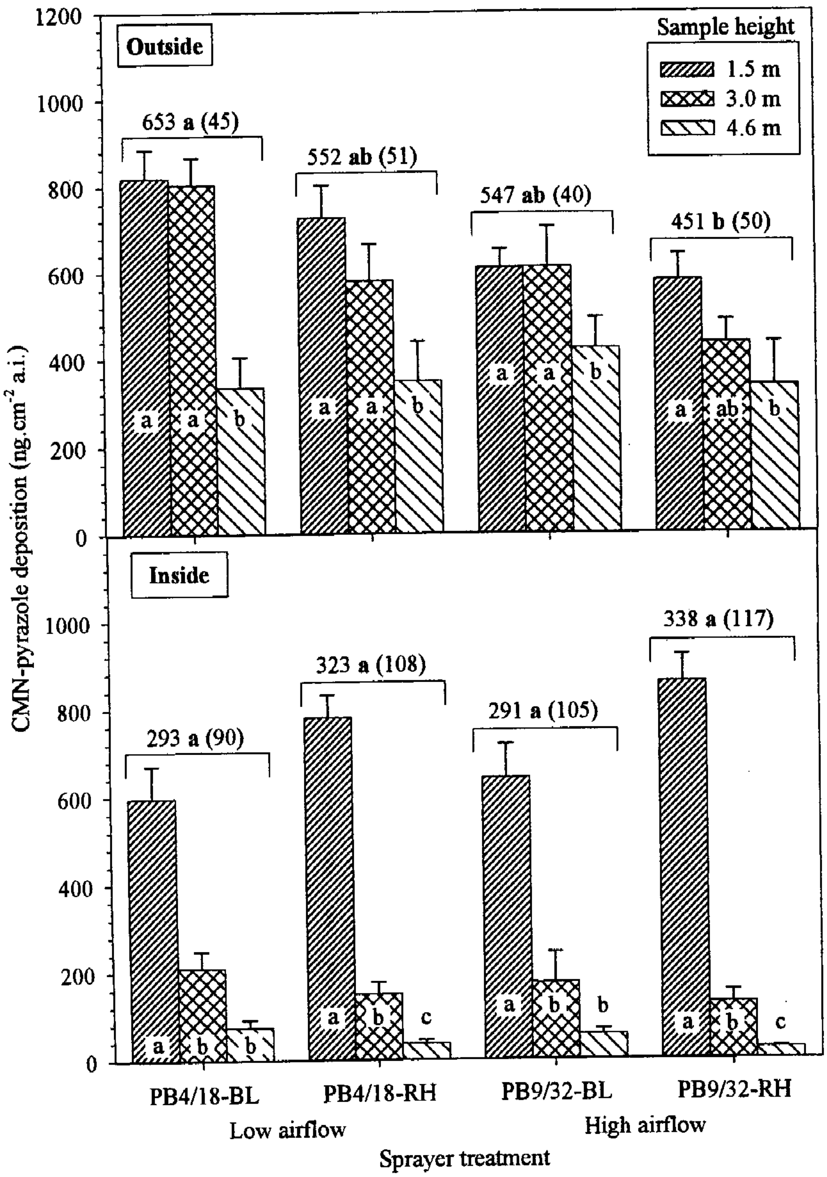


Fig. 4. Comparison of deposition inside and outside at three heights from PowerBlast treatments; boldface and regular letters separate means between and within treatments, respectively; numbers in parentheses are respective coefficients of variation; PB 4/18 and PB 9/32 = PowerBlast four-blade 18° fan and nine-blade 32° fan, respectively; BL = Albuz blue nozzle for higher output; RH = Albuz red nozzle for lower output; 1.0 m = 3.28 ft, 1 ng·cm^{-2} = 2.3 × 10^{-10} oz/inch^2.

level than at other levels whereas for lower nozzle output, the inside deposition was different at three heights.

Fruit detachment force. The mean FDF from all four treatments was significantly less than the force in control plots (Fig. 5). However, no difference existed among spray treatments. For all treatments, the FDF was lower at 1.5 m height than at 4.6 m height. There was a strong correlation between FDF and spray deposition at 4.6 m height (Table 2).

Fruit removal. Although all spray treatments numerically increased PFR over the control, only the effect of PB4/18-RH was significant. The response of PFR to treatments did not correspond to spray deposition. This effect was indicated by weak correlation ($r = 0.29$, $P > 0.1$) between deposition and fruit removal (Table 2). The PFR by PB4/18-RH was slightly (but non-significantly) higher than the other three treatments that had similar percentage of fruit removal. There was also poor correlation between FDF and PFR for these sprays (Table 2). The lack of relationship between deposition and PFR might have been related to shaking parameters, and to the extent the trees were shaken. Vigorous shaking of the trees could have masked the effect of the abscission chemical.

Experiment 2: Titan Sprayer

Deposition. Overall, mean deposition of the T22-DF (higher airflow and higher nozzle output) was significantly lower than the other treatments (Fig. 6). The lower airflow (T16) gave similar or higher mean deposition than higher airflow (T22). At lower airflow, nozzle output did not affect mean deposition while at higher airflow, the lower nozzle output (CS) gave higher mean deposition than the higher nozzle output (DF). Within all treatments, the height affected the deposition and it was lowest at 3.0 m height (Fig. 6). This result could be attributed to the sprayer nozzle arrangement and airflow direction. At 1.5 m level, treatment T16-DF gave higher deposition than other treatments (Fig. 7). At 3.0 m level, all treatments gave similar deposition whereas at 4.6 m, the treatment T22-CS gave higher deposition than T22-DF.

Overall, there was higher and more uniform deposition outside the canopy than on inside the canopy (Fig. 8). On the outside, the higher airflow resulted in lower mean deposition than the lower airflow, probably due to runoff from leaf surface. For all treatments (except T16-DF) the depositions at all heights were statistically similar. Inside, the overall mean deposition was not affected by the treatments. Deposition at 1.5 m height was mostly higher than at other heights.

Comparison of the two experiments revealed that mean spray deposition of the Titan sprayer was higher and less variable than spray deposition of the PowerBlast sprayer. Variation in deposition at different canopy heights was less with the Titan. In general, deposition at 1.5 and 4.6 m heights was higher from Titan treatments than from PowerBlast treatments. At 3.0 m (10 ft) height, the trend was reversed.

Fruit detachment force. The FDF from the sprayed treatments was significantly less than the FDF from nonsprayed control (Fig. 9). Differences also existed between some of the four treatments. At both airflow rates, the higher nozzle output (DF) resulted in higher FDF than the lower nozzle output (CS). The detachment force at both heights had strong correlation

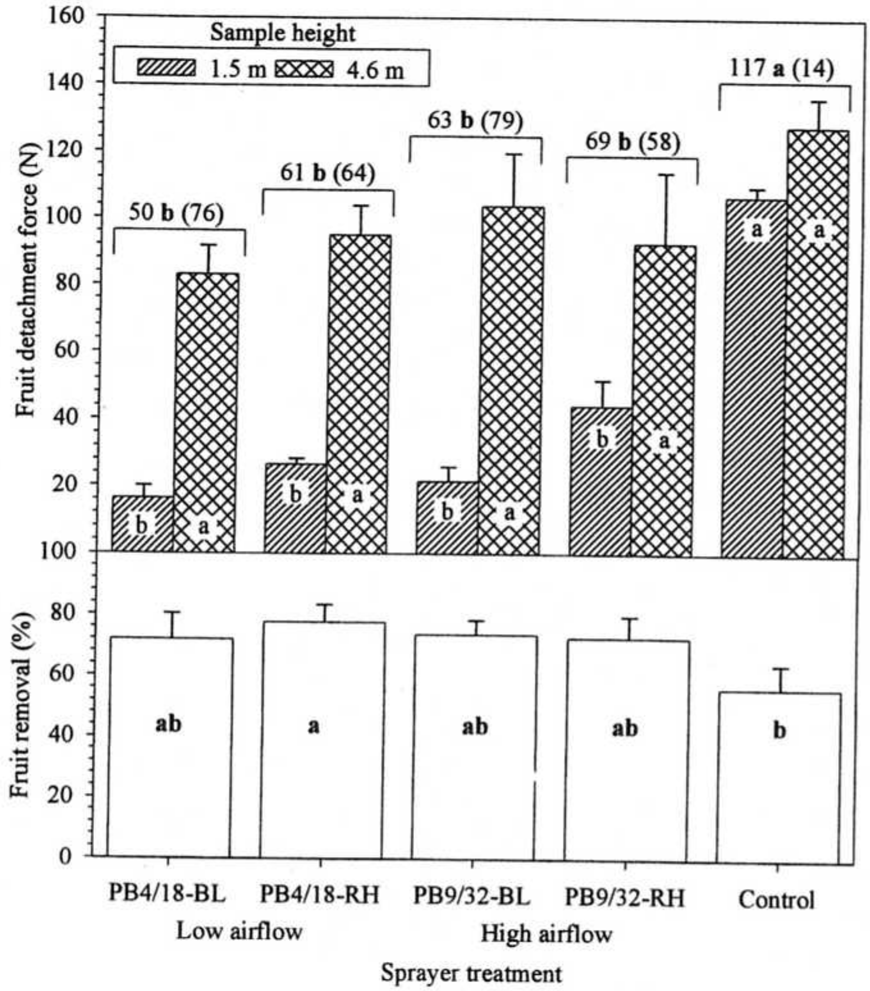


Fig. 5. Fruit detachment force (top) and fruit removal (bottom) for PowerBlast treatments; boldface and regular letters separate means between and within treatments, respectively; numbers in parentheses are respective coefficients of variation; PB 4/18 and PB 9/32 = PowerBlast four-blade 18° fan and nine-blade 32° fan, respectively; BL = Albuz blue nozzle for higher output; RH = Albuz red nozzle for lower output; 1.0 m = 3.28 ft, 1 N = 0.225 lb force.

Table 2. Correlation among deposition, fruit detachment force and fruit removal for two experiments to investigate the effect of sprayer type, airflow rate, and nozzle output on deposition of active ingredient and mechanical harvesting of 'Valencia' orange in Crewsville, Fla.

Variable	Fruit detachment force			Fruit
	1.5 m	4.6 m	Overall	removal
Expt. 1: PowerBlast sprayer				
CMN-pyrazole deposition				
1.5 m	-0.32^{NS}			0.28^{NS}
4.6 m		-0.90^{**}		0.38^{NS}
Overall			-0.87^{**}	0.37^{NS}
Fruit detachment force				
1.5 m				-0.01^{NS}
4.6 m				-0.32^{NS}
Overall				-0.21^{NS}
Expt. 2: Titan sprayer				
CMN-pyrazole deposition				
1.5 m	-0.78^{**}			0.30^{NS}
4.6 m		-0.78^{**}		0.26^{NS}
Overall			-0.84^{**}	0.29^{NS}
Fruit detachment force				
1.5 m				-0.44^{NS}
4.6 m				-0.23^{NS}
Overall				-0.34^{NS}

$^{NS, **}$Nonsignificant at $P = 0.05$ or significant at $P = 0.01$.

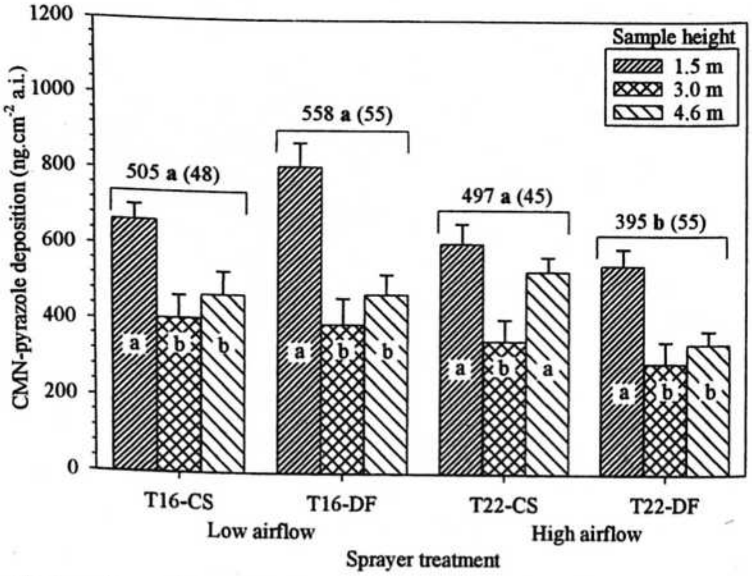


Fig. 6. Comparison of deposition at three heights from each Titan treatment; boldface and regular letters separate means between and within treatments, respectively; numbers in parentheses are respective coefficients of variation; T16 and T22 = Titan operating at 1600 and 2225 rpm, respectively; CS = Conejet nozzle for lower output; DF = disc-core nozzle for higher output; 1.0 m = 3.28 ft, 1 ng·cm^{-2} = 2.3 × 10^{-10} oz/inch^2.

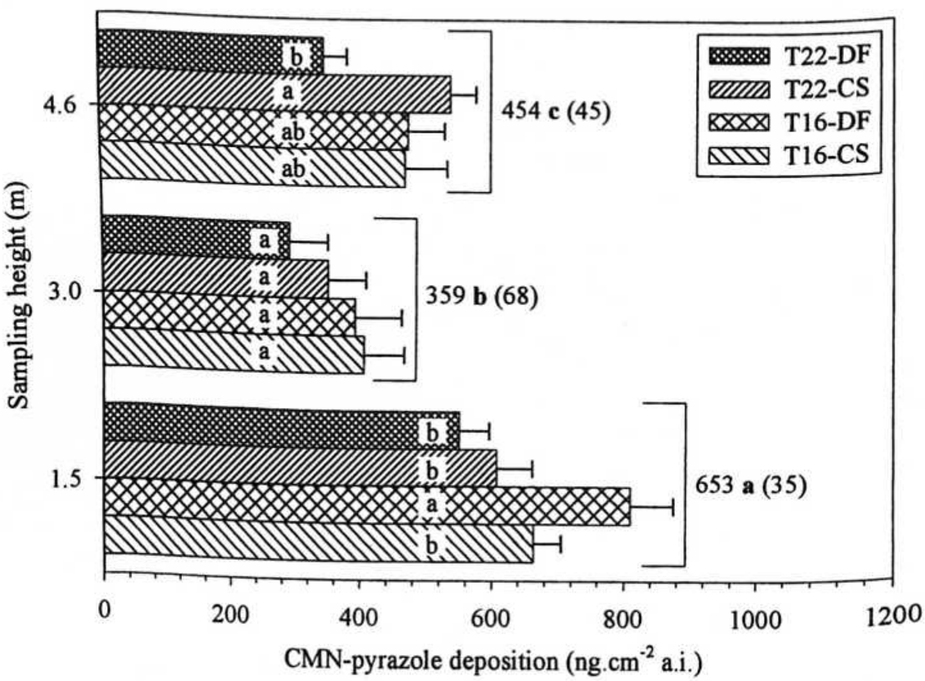


Fig. 7. Comparison of deposition from Titan treatments at each height; boldface and regular letters separate means between and within treatments, respectively; numbers in parentheses are respective coefficients of variation; T16 and T22 = Titan operating at 1600 and 2225 rpm, respectively; CS = Conejet nozzle for lower output; DF = disc-core nozzle for higher output; 1.0 m = 3.28 ft, 1 ng·cm^{-2} = 2.3 × 10^{-10} oz/inch^2.

($r = -0.78$, $P < 0.01$) with the deposition (Table 2).

Fruit removal. None of the Titan treatments significantly increased the fruit removal over the control. The response of PFR to treatments did not correspond to spray deposition as explained in PowerBlast applications. This effect is indicated by weak correlation ($r = 0.29$, $P > 0.1$) between deposition and fruit removal (Table 2). There was also a poor correlation ($r = -0.34$, $P > 0.1$) between FDF and PFR for these sprays.

The FDF for Titan sprayer treatments (Fig. 9) was generally lower than that for PowerBlast sprayer treatments (Fig. 5). The percent removal of fruit using the trunk shaker resulted in higher percentage of removal for the Titan than for the PowerBlast. However, comparison of Figs. 5 and 9 indicated that the enhancement in percent of fruit removal from the level of the non-sprayed control was less in case of Titan sprayer than the PowerBlast sprayer.

Conclusions

- Spray delivery over the entire canopy resulted in more deposition than the low profile radial delivery (standard air-blast) system.
- With the PowerBlast and Titan sprayers, lower airflow resulted in comparable deposition to the higher airflow. Using lower airflow could reduce the fan energy requirement of the sprayers by 66.6% and 62.8%, respectively.
- With PowerBlast sprayer, nozzle output did not affect the deposition.
- With the Titan sprayer, the deposition was not affected by the nozzle output at lower airflow.
- Fruit detachment force was significantly less on sprayed trees than non-sprayed control.
- Abscission sprays were partially effective in enhancing percent fruit removal. However, the relationships between deposition or FDF and PFR were nonsignificant.