

IMPROVING EFFICACY OF ABSCISSION SPRAYS FOR MECHANICAL HARVESTING OF ORANGES

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Abstract. Two studies were conducted in commercial orange groves in central and south Florida with the overall objective of reducing the cost of application while increasing the efficacy of the abscission chemical sprays. In the first study to find optimum airflow rate, the fan speed of an air-blast (Titan) tower sprayer was varied from 1600 to 2200 rpm to achieve different airflow rates. In the second study, a drift retardant adjuvant (In-Place) was used in the tank mix with and without a surfactant adjuvant at two liquid flow rates to enhance the efficacy of low volume applications with a Curtec tower sprayer. In both studies, the spray mixture contained 5-chloro-3-methyl-4-nitro-1-H-pyrazole (Release), an experimental abscission material, and a fluorescent tracer. Spray deposition was sampled at different canopy locations and quantified by fluorometry. Harvesting efficacy was quantified by measuring fruit detachment force (FDF), percent fruit drop (PFD) and percent fruit removal (PFR) by a trunk shaker. With the Titan sprayer, none of the spray treatments resulted in significantly different percent fruit removal than the unsprayed control. With the Curtec sprayer, the use of a drift retardant adjuvant was effective in reducing fruit detachment force. Percent fruit removal significantly increased with addition of a surfactant (Kinetic®). It appears that the economics and efficacy of the abscission chemical applications may be improved by using lower airflow rates and certain adjuvants.

Florida citrus growers are facing tough competition from international rivals (Anonymous, 2002). Increased production efficiency and reduced costs can provide growers an edge over their competitors. Mechanical harvesting of citrus has the potential for increasing efficiency and reducing costs (Brown, 2001). Abscission materials are considered important for the future success of mechanical harvesting (Salyani et al., 1999). These materials may loosen fruit by reducing the fruit detachment force (FDF) and thus enhance fruit removal efficiency of trunk shakers (Whitney et al., 2000). Application of these materials must be effective, economical, and environmentally safe.

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In orchard applications, air-carrier sprayers that direct the spray to trees and improve penetration into dense canopies have proven to be effective (Bache and Johnston, 1992). Various aspects of spray application with air-carrier sprayer have been studied. Salyani and Hoffman (1996) investigated the effect of air velocity from air-carrier sprayers on leaf target spray deposition in an open area grid. They found little or no correlation between air velocity and deposition on leaf samples. Similar results were reported from Derksen and Gra (1995). Koo et al. (2000) compared application efficacy of air blast and air-curtain sprayers using an abscission material for mechanical harvesting of citrus at two application volumes. The air-blast sprayer resulted in more deposition on the lower canopy while the air-curtain sprayer deposited more on the upper canopy, but harvesting efficiency with a trunk shaker did not differ between sprayers. Salyani et al. (2000) studied the effect of spray discharge rate of an air-blast sprayer and ground speed on deposition on leaf targets in an open area. Sprayer air velocity at the sampling locations was measured and found to decrease with increasing ground speed. In general, lower spray discharge rate resulted in higher deposition and was attributed to increased run-off from the surface of the leaf targets at higher spray discharge rates. The higher ground speeds resulted in higher deposition at both high and low spray discharge rates. It was speculated that the decrease in sprayer air velocity with increasing ground speed could have been partly responsible for higher deposition by reducing run-off at higher speeds. Farooq et al. (2002) investigated the effect of airflow rate from low-profile and tower air-blast sprayers on deposition and efficacy of abscission materials for mechanical harvesting of citrus. They found that lower airflow resulted in similar deposition and harvesting efficacy as the normal higher airflow. Salyani et al. (2002) did not find any effect of airflow rate on deposition or on harvesting efficiency. In summary, higher air velocities in air-blast sprayer applications may not only be ineffective but also damaging to the environment by dislodging more spray from the target and increasing drift. Airflow rates need to be investigated to determine the optimum for such applications. The first study was aimed at finding an optimum airflow rate for application of abscission materials to citrus using an air-blast tower sprayer.

Low-volume spraying can allow a reduced volume of water to be used, improve timeliness and work rates, and reduce chemical application costs; however, it may increase drift risk. Different combinations of nozzle size, number of nozzles, and ground speed were studied to find the optimum deposition efficiency of the air-blast sprayers (Salyani, 2000a). For low volume applications, the use of fewer, smaller nozzles at lower speed was more effective than using more nozzles at higher speeds. In some studies on abscission material application for mechanical harvesting of citrus, deposition was higher with lower volume rate (BenSalem et al., 2001; Koo et al., 1999; Koo et al., 2000; Salyani et al., 2002). However, higher deposition of low-volume applications did not translate into higher harvesting efficacy with a trunk shaker. Full benefits of low-

volume applications can only be achieved when the efficacy of the applied material is maintained or improved. The second study was conducted to determine if specific adjuvant types would improve efficacy achieved with low-volume application using an air-curtain sprayer.

Materials and Methods

Study 1: Airflow Test

This study was conducted in a commercial grove of *Citrus sinensis* Osbeck cv. Parson Brown, near Crewsville, Fla. in Jan. 2002. The 5.5 to 6.5 m high trees were planted in two-row beds. The tree spacing alternated between 3.0 and 4.6 m in the row and 6.7 and 7.8 m across the bed and ditch, respectively. An air-blast tower sprayer (Titan 1093, John Bean Sprayers, Hogansville, Ga.) equipped with an axial-flow fan and 34 disc-core (D4-23) nozzles per side was used. The sprayer was operated at fan speeds of 1600 to 2200 rpm to obtain different airflow rates (Table 1). Nozzle pressure and ground speed were adjusted to maintain an application rate of 1830 L·ha⁻¹ for all the treatments. The four spray treatments and a non-sprayed control were replicated four times using a randomized complete block design. Each plot consisted of four trees. The middle two trees were used for sampling while the outer trees were treated as buffer.

The spray mixture contained an experimental abscission material (5 Chloro-3-methyl-4-nitro-1-H-Pyrazole (CMN-P), 17.18% a.i. (w/w) Abbott Laboratories, Chicago, IL) at 230 mg·L⁻¹, a surfactant adjuvant (Kinetic®, Helena Chemical Co., Memphis, Tenn.) at 0.1% v/v, and a fluorescent tracer (Pyranine-10G, Keystone Aniline Inc., Chicago Ill.) at 250 ppm. The trees were sprayed on both sides (Fig. 1).

Study 2: Adjuvant Test

This study was conducted in a commercial grove of *Citrus sinensis* Osbeck cv. Hamlin near La Belle, Fla. in Feb. 2002. The trees were about 5.5 m high in two-row beds. The spacing was 7.3 m between the rows and 4.9 m between the trees. An air-curtain tower sprayer (Curtec 648, BEI, Inc., South Haven, Mich.) equipped with three cross-flow fans and two rotary atomizers per fan on each side was used. The sprayer was used at liquid flow rates of 126 (Low) and 378 (High) mL·sec⁻¹ (Ta-

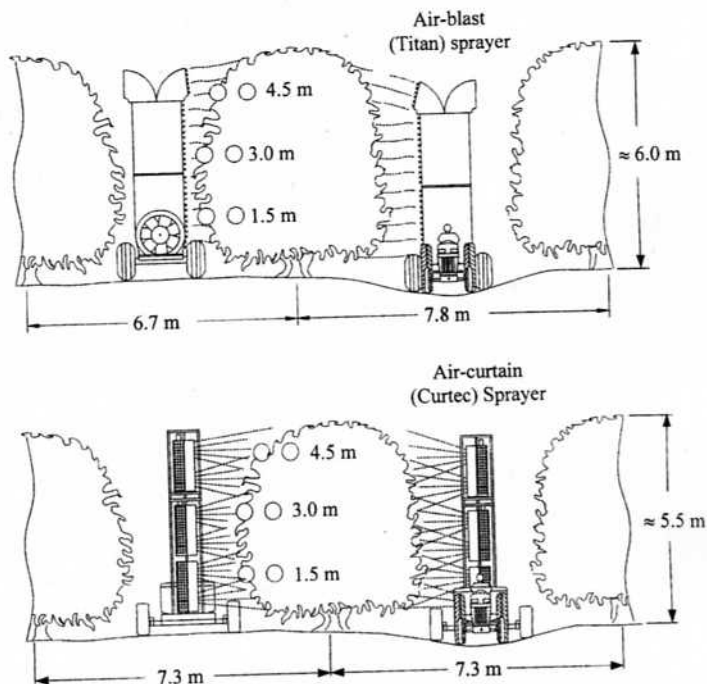


Fig. 1. Spray application and sampling layout for airflow (top) and adjuvant (bottom) tests (Leaf samples for deposition analysis were taken at the 1.5, 3.0, and 4.5 m canopy heights where shown by 'O').

ble 1). The spray mixture contained CMN-P at 545 mg/liter, drift retardant adjuvant (In-Place, Wilbur Ellis Co. Fresno, Calif.) at 136 mg/liter, and fluorescent tracer Pyranine-10G at 400 ppm. Two treatments also contained Kinetic® at 0.1% v/v. The sprayer ground speed was varied to maintain a constant volume rate of 770 L·ha⁻¹. The four spray treatments and a non-spray control were replicated four times using a randomized complete block design. Each plot consisted of three trees with a sampling tree in the center surrounded by two buffer trees. The trees were sprayed on both sides (Fig. 1).

Methodology for Studies 1 and 2. After the spray dried, leaf samples were collected from the middle trees. Leaves were collected from outside and inside (outer surface and 0.6 to 0.8 m inside the outer surface, respectively) at three heights (Fig. 1) and two quadrants (leading and trailing positions c-

Table 1. Definition of treatments.

Sprayer treatments ^a	Airflow rate ^b (m ³ ·sec ⁻¹)	Nozzle flow rate (mL·sec ⁻¹)	Ground speed (km·hr ⁻¹)	Volume rate (L·ha ⁻¹)	CMNP a.i.conc. (mg·L ⁻¹)	Kinetic (% v/v)	In-Place (mg·L ⁻¹)
Study 1: Airflow test with Titan							
T16	28	562	3.0	1830	230	0.1	
T18	31	600	3.2	1830	230	0.1	
T20	34	600	3.2	1830	230	0.1	
T22	37	600	3.2	1830	230	0.1	
Study 2: Adjuvant test with Curtec							
CL		126	1.6	770	545	0.0	136
CH		378	4.8	770	545	0.0	136
CLS		126	1.6	770	545	0.1	136
CHS		378	4.8	770	545	0.1	136

^aTreatment Coding: Study 1 (T = Air-blast sprayer (Titan); 16, 18, 20, 22 = Fan speed of 1600, 1800, 2000 and 2200 rpm); Study 2 (C = Air-curtain sprayer (Curtec); L = Low liquid flow; H = High liquid flow; S = Presence of Kinetic surfactant with In-Place drift retardant).

^bThe fan inlet airflow was measured at 64 cross-sectional nodes using a hot film anemometer.

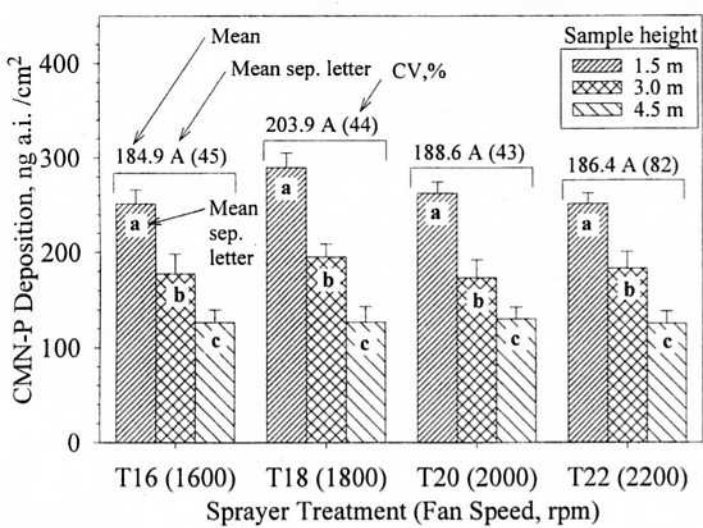


Fig. 2. Effect of canopy heights on mean deposition for Titan sprayer treatments in study 1 (Uppercase and lower case letters separate means between and within treatments, respectively).

application) of the sampling tree. The leaf samples (three to five leaves) were placed in sealable plastic bags, stored in an insulated container in the field and then transferred to a refrigerator at 4 °C until analyzed. The samples were washed with de-ionized water and tracer concentration was quantified using fluorometry (Salyani, 2000b). Leaf area was measured with an area meter (Delta-T Devices Ltd., Cambridge, UK). CMN-P deposition was calculated from tracer deposition and the two were assumed proportional.

Five days after spraying, fruit detachment force (FDf) for randomly selected fruits from the sampling trees at 1.5 and 4.5 m heights (five fruits per height), was measured with a pull force gauge (model FDV-50, Wagner Instrument, Greenwich, Conn.). These fruits were weighed and the average fruit weight per plot was determined. The abscission-induced fruit drop was counted. The count was converted to fruit drop weight using respective average fruit weight. In the airflow test, trees were shaken for 5 sec with an FMC linear trunk

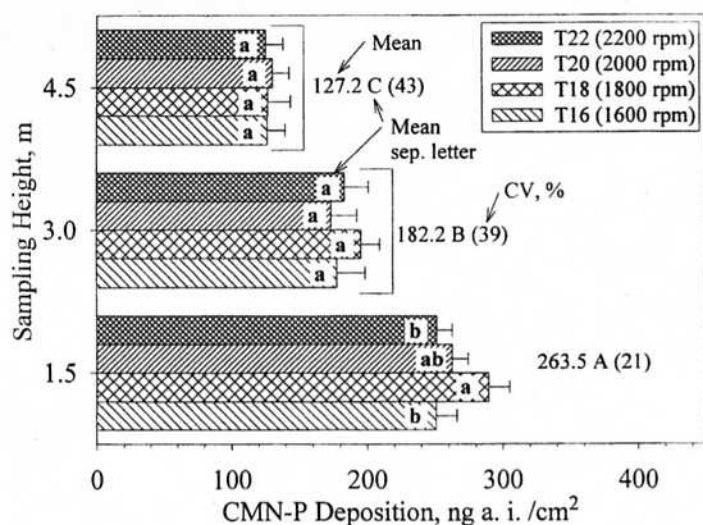


Fig. 3. Effect of Titan sprayer treatments on mean deposition at each height in study 1 (Uppercase and lowercase letters separate means between and within heights, respectively).

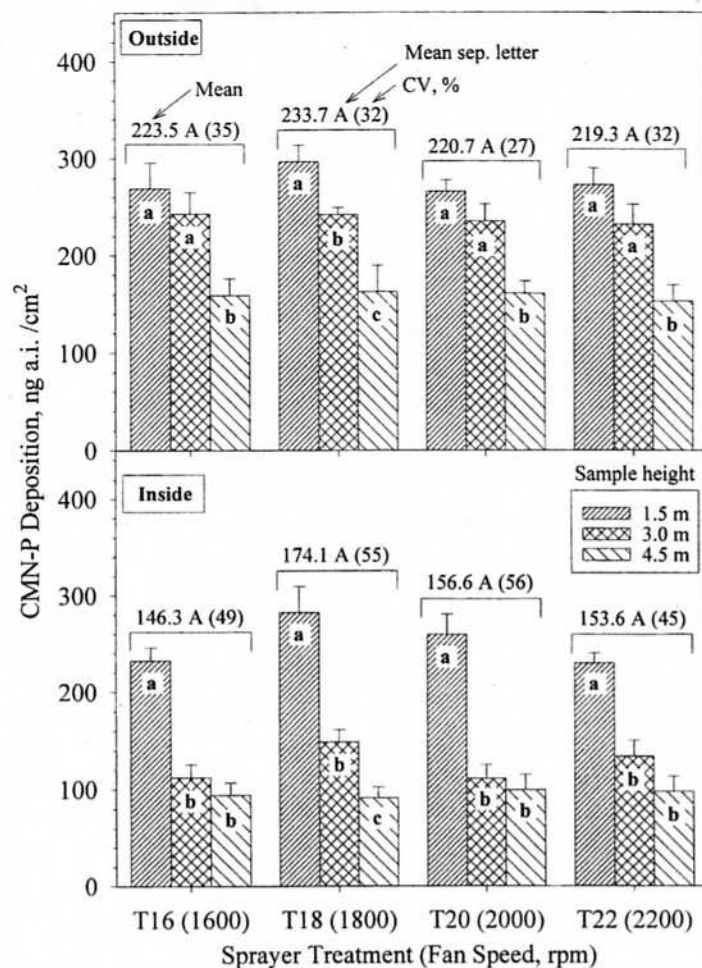


Fig. 4. Effect of canopy heights on mean deposition for Titan sprayer treatments inside and outside the canopy in study 1 (Uppercase and lowercase letters separate means between and within treatments, respectively).

shaker, which has a shake displacement of 5 cm at 8 Hz. In the adjuvant test, trees were shaken for 5 sec with an Orchard Rite multidirectional trunk shaker, which has 7 cm displacement at 8 Hz. The removed fruit were collected and weighed. Remaining fruits were picked manually and weighed. The percent fruit drop (PFD), percent fruit removal (PFR) and fruit yield (FY) were determined from the weights of dropped, removed and hand picked fruits.

The mixed procedure (PROC MIXED) with LSMEANS and PDIF options was used to analyze the data (Littell et al., 1996). The means were separated by the t-test at the 5% level of significance. Standard error (SE) and coefficient of variation (CV) expressed variability in the data. The correlations procedure (PROC CORR) of SAS (SAS Institute, 1990) was used to find relationship between spray deposition and harvesting parameters (fruit detachment force, percent fruit drop and percent fruit removal).

Results and Discussion

Study 1: Airflow Test

Spray Deposition. Overall mean deposition of CMN-P was highest at fan speed of 1800 rpm (T18), but the difference in mean deposition between four treatments was not significant

(Fig. 2). Within each fan-speed setting, deposition decreased with increase in canopy height, primarily due to the presence of denser canopy at higher levels. This was consistent with observations by Koo et al. (1999) and Salyani et al. (2002). At the 1.5 m height, T18 resulted in significantly higher deposition than some other treatments whereas at other heights, the depositions from treatments were similar (Fig. 3). The trend in variation of mean deposition from four fan-setting treatments on the outer and inner canopy was similar to that of the overall mean deposition (Fig. 4). Outside, the deposition at the 1.5 and 3.0 m heights within treatments except T18 was higher than the deposition at the 4.5 m height. Inside, the deposition at the 1.5 m height within treatments except T18 was higher than the deposition at the other heights. Inside the canopy at the 1.5 m height, T18 resulted in significantly higher deposition than T16 and T22 treatments (Fig 4) whereas inside at the other two heights, and outside at all three heights, there was no difference in deposition between the four treatments. In general, 31 m³·sec⁻¹ airflow rate at the fan speed of 1800 rpm resulted in slightly (non-significantly) higher deposition than the other fan speeds. This indicated that there was no deposition benefit in using fan speed higher than 1800 rpm for this sprayer. Since energy demand of the sprayer fan increases (or decreases) by cube of the fan rpm or airflow, decreasing the fan speed to 1800 rpm would lead to reduction in energy consumption of this sprayer by over 45% [= 100 {1 - (1800 / 2200)³}].

Harvesting. All spray treatments resulted in significantly lower fruit detachment force (FDF) than the non-sprayed control with treatment T18 resulting in a lower FDF than other sprayer treatments (Fig. 5). Within treatments, the FDF was lower at the 1.5 m height than at the 4.5 m height as also found by Koo et al. (1999) and Farooq et al. (2002) but the difference was significant only for T18. Comparison of Figs. 2 and 5 showed that the difference in deposition between the

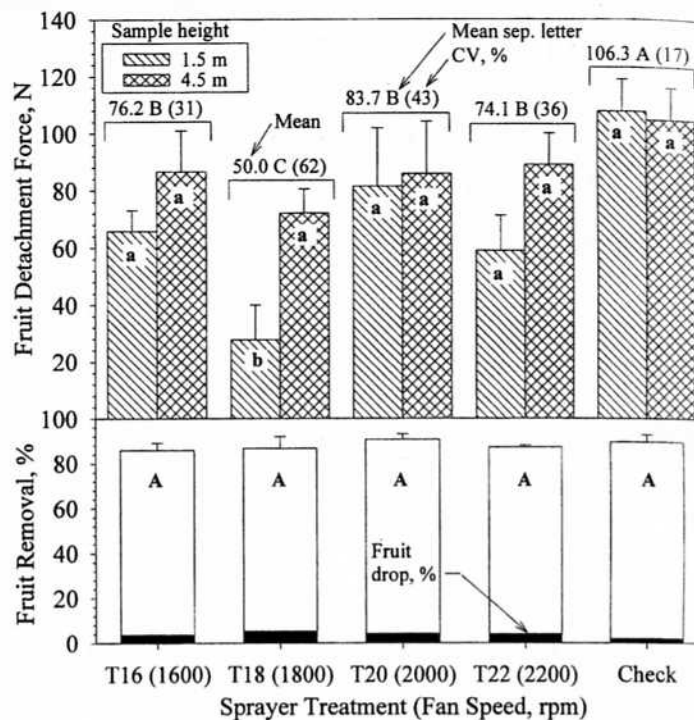


Fig. 5. Fruit detachment force (top), percent fruit drop and percent fruit removal (bottom) for Titan sprayer treatments in study 1 (Upper and lower case letters separate means between and within treatments, respectively).

heights, in general, was reflected in the FDF measurement. This was also indicated by the correlation ($r = -0.53$, $P = 0.05$) between deposition and FDF (Table 2). Tree characteristics pertinent to fruit removal by the shaker were measured: Clamp height (CHT), trunk circumference (CIR) at clam height and fruit yield (FY) averaged 32.0 cm, 71.5 cm, an

Table 2. Correlation among deposition and harvesting parameters^a.

Variable	Fruit detachment force			Percent fruit drop	Percent fruit removal
	1.5 m	4.5 m	Overall		
Study 1: Airflow test with Titan					
CMN-P deposition	1.5 m	-0.59**		0.71**	-0.12 ^{ns}
	4.5 m		-0.15 ^{ns}	0.70**	-0.20 ^{ns}
	Overall			0.72**	0.15 ^{ns}
Fruit detachment force	1.5 m			-0.61**	-0.29 ^{ns}
	4.5 m			-0.26**	-0.01 ^{ns}
	Overall			-0.53*	-0.19 ^{ns}
Clamp height				-0.03 ^{ns}	0.36 ^{ns}
Trunk circumference				-0.10 ^{ns}	-0.37 ^{ns}
Fruit yield				-0.30 ^{ns}	-0.41 ^{ns}
Study 2: Adjuvant test with Curtec					
CMN-P deposition	1.5 m	-0.49*		0.67**	0.57**
	4.5 m		-0.74**	0.55*	0.44 ^{ns}
	Overall			0.64**	0.54*
Fruit detachment force	1.5 m			-0.64**	-0.27 ^{ns}
	4.5 m			-0.50*	-0.35 ^{ns}
	Overall			-0.64**	-0.35 ^{ns}
Clamp height				-0.12 ^{ns}	0.20 ^{ns}
Trunk circumference				-0.20 ^{ns}	-0.30 ^{ns}
Fruit yield				-0.19 ^{ns}	-0.38 ^{ns}

^aSignificance level: ** = 1%, * = 5%, ns = not significant at 5%.

