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BETTER SPRAY COVERAGE CAN IMPROVE EFFICACY OF ABSCISSION SPRAYS FOR MECHANICALLY HARVESTED ORANGES

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Abstract. **The selective fruit abscission compound 5-chloro-3-methyl-4-nitro-1*H*-pyrazole (CMNP) improves mature fruit removal of mechanically harvested orange trees in Florida. Uniform fruit removal depends on peel contact by CMNP sprays. When conventional radially discharging air-blast (AB) sprayers are used, fruit removal is variable, especially in tall dense canopies. Fruit detachment force (FDF) and fruit removal were measured when CMNP was applied with an AB or a multi-head air-blast 'GreenTech' (GT) sprayer. CMNP (200 ppm [200 mg·L^{-1}]) was applied at 1873 and 2810 L·ha^{-1} (200 and 300 gal·acre^{-1}) with the AB or GT sprayers to 'Hamlin' orange [*Citrus sinensis* (L.) Osb.] in Immokalee, Fla. A second trial was conducted in 'Valencia' orange in Immokalee that included a 1405 L·ha^{-1} (100 gal·acre^{-1}) application. Four days after treatment, FDF at heights of 1, 2, and 4 m (approx. 3', 6', and 12') at inside and outside canopy positions were determined. Fruit from GT-sprayed trees had lower and more uniform FDF at all canopy positions. In contrast, fruit from AB-sprayed trees had greater variability in FDF, especially at the top and inside the canopy. Fruit were mechanically harvested using a trunk shake-and-catch system. Mature fruit removal was greater and less variable in GT-sprayed than AB-sprayed trees and required less spray volume. The results demonstrate that uniform CMNP coverage can minimize variation in its efficacy and improve mature fruit removal of trees harvested with a trunk shaker.**

The abscission compound 5-chloro-3-methyl-4-nitro-1*H*-pyrazole (CMNP) is a selective, non-phytotoxic agent currently being registered as an aid to mechanical harvesting of Florida citrus. CMNP applications have been shown to reduce the force necessary to remove mature fruit (fruit detachment force, FDF) enabling mechanical harvesters to increase harvest speed without compromising fruit removal (Burns et al., 2005). CMNP application in late May followed by machine harvest at low frequency removed a high percentage of mature fruit, reduced removal of young green fruit, and thus preserved the following season's yield (Burns et al., 2006). CMNP has proven to be a valuable tool to improve machine capacity and allow late season 'Valencia' harvest.

The ability to uniformly apply CMNP throughout the tree canopy remains an important goal. Since efficacy of CMNP has been shown to depend on peel contact (Alferez et al., 2005), uniform application of CMNP in the canopy should maximize its efficacy and fruit removal. In working observations, application of CMNP at 300 gal•acre^{-1} using conventional radially-discharging air-blast sprayers did not adequately penetrate the canopy and cover fruit located in the internal and upper portions of the tree. This resulted in poor fruit removal with mechanical harvesters from these locations. There was reduced spray penetration with air-blast sprayers at increasing tree heights and canopy depths (Farooq et al., 2003). The use of tower-type sprayers to reduce the distance between application nozzles and the canopy resulted in variable penetration on the inside and outside of the canopy (Farooq and Salyani, 2002; Farooq et al., 2003; Salyani et al., 2002). Application volumes in excess of 900 gal·acre^{-1} were used to assure adequate and uniform fruit loosening to achieve more uniform coverage and increased fruit removal (Whitney, 1975, 1976). The logistical complications arising from spraying in excess of 900 gal•acre^{-1} would increase abscission application costs and potentially impede the widespread use of CMNP or other abscission agents. Improving spray penetration throughout the canopy while minimizing spray volume are necessary goals to reduce within-tree variation, increase overall fruit removal, and maximize grower returns through lower harvesting costs.

During the 2005-2006 orange harvesting season, OXBO International introduced a multi-head air-blast sprayer called 'GreenTech' (Clear Lake, Wis.). The 'GreenTech' sprayer represented an alternative spray technology to the standard air-blast sprayer. This paper reports on two trials that compared within-tree variation of FDF and fruit removal between the 'GreenTech' sprayer and a conventional radially discharging air-blast sprayer.

Materials and Methods

Two trials were conducted in Immokalee, Fla., during the 2005-2006 citrus harvest season. The first trial was conducted at Silver Strand North block C-13. Sixty uniform trees of 'Hamlin' orange (*Citrus sinensis* [L.] Osbeck) on Swingle citrumelo (*Citrus paradisi* × *Poncirus trifoliata*) rootstock were selected for study. The 17 year-old trees were spaced at 3.6 m in the row and 7.3 m between rows (380 tree / ha) and averaged 4.4 m in height and 4.2 m in canopy diameter. Trunk circumference averaged 0.5 m at the trunk shaker-tree trunk attachment point (~0.25 m above the soil line). Canopy skirt heights were maintained at 1.1 m as a normal cultural practice. Trees were divided into 20 three-tree plots separated by at least two guard trees in the row.

A second trial using 'Valencia' orange was conducted at Silver Strand III, block E-3. Trees were on Swingle rootstock and were 20 years of age. Eighty-four uniform trees at a spacing of 3 m × 6.5 m (445 tree / ha) were selected. Average tree

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height was 4.2 m, diameter was 3.8 m, and trunk circumference was 0.4 m. Skirts were maintained at 0.8 m at this location. Trees were divided into 28 three-tree plots separated by at least two guard trees in the row. Treatments described below were replicated four times and randomly assigned to plots.

In all cases, CMNP (17.2% a.i., as previously formulated by Abbott Laboratories, Chicago, Ill.) was used as the abscission agent and applied at 200 $mg\cdot L^{-1}$. Spray solutions contained 0.05% (vol/vol) of Kinetic adjuvant (Helena Chemical Co., Memphis, Tenn.). Spray applications were made using a conventional radially-discharging air-blast (AB) sprayer (model MB-400-36 Pul-Blast, Rears Manufacturing Co., Eugene, Ore.) or a multi-head air-blast 'GreenTech' (GT) sprayer (4000L model, OXBO International, Clear Lake, Wis.; Fig. 1). The AB sprayer was equipped with seven Albuz blue ceramic nozzles (Ceramiques Techniques Desmarquest, Evreux, France) operating at 180 to 220 psi. The GT sprayer had two 5.5 m (18') vertical booms, each with six independently-powered high volume electric-driven fan assemblies. Each boom had two hydraulic adjustment points that allowed articulation to the canopy contour of one side of a tree. Each fan assembly contained eight Conejet #12 nozzles (Spraying Systems Co., Wheaton, Ill.) operating at 165 psi. To achieve volume treatments of 300, 200 $gal\cdot acre^{-1}$ (2810 and 1873 $L\cdot ha^{-1}$) in 'Hamlin' and 'Valencia', and 100 $gal\cdot acre^{-1}$ (1405 $L\cdot ha^{-1}$) in 'Valencia', ground speed was 1.0, 1.6, and 3.5 mph (1.6, 2.5, and 5.6 $km\cdot h^{-1}$) for the AB sprayer and 1.3, 2.2, and 3.0 mph (2.0, 3.5, and 4.8 $km\cdot h^{-1}$) for the GT sprayer, respectively. An unsprayed control was included in each trial. Thus, the total number of treatments in the 'Hamlin' and 'Valencia' trials was five and seven, respectively.

Sprays were applied on 9 Jan. 2006 and 27 Mar. 2006 for 'Hamlin' and 'Valencia' trials, respectively. Four d after CMNP application, FDF of 10 randomly selected fruit was measured at heights of 1, 2, and 4 m (approx. 3', 6', and 12') at inside (0.3 m [1'] from trunk) and outside (within 0.3 m of the canopy edge) canopy positions. FDF was measured using a Force One digital force gauge (Wagner Instruments, Greenwich, Conn.) as described previously (Pozo et al., 2004). Mechanical harvesting was accomplished using a trunk shake-and-catch system (Coe-Collier Citrus Harvesting, LLP, Immokalee, Fla.). Each tree was shaken for 5 s at about 8 Hz using full engine throttle (>4,000 rpm). Fruit from each plot harvested by the trunk shaker was caught in the catch frame (MH fruit) and manually bagged and weighed in the 'Hamlin' trial or conveyed into a goat equipped with a weighing scale in the 'Valencia' trial. Fruit not caught in the catch frame (ground fruit) were manually bagged and weighed. Fruit remaining in the canopy after trunk shaking (gleaned fruit) were removed, bagged, and weighed. Mature fruit removal percentage was calculated by dividing the weight of MH fruit + ground fruit by the total yield (MH fruit + ground

Fig. 1. The air-blast (left panel) and 'GreenTech' (right panel) sprayers used in these studies.

fruit + gleaned fruit) × 100. Mature fruit recovery percentage was calculated by dividing the weight of MH fruit by the total yield × 100. Percentage recovery was not calculated in the 'Hamlin' trial because of problems with the catch frame.

Data were analyzed as a completely randomized design. Analysis of variance was performed using the SAS statistical package. Percentage data were transformed when necessary to normalize the distribution of variance. Means were separated using Duncan's multiple range test at $P \leq 0.05$.

Results

'Hamlin' trial. When the GT sprayer was used at any volume, no differences were found in FDF at any tree height or canopy depth (Fig. 2). In contrast, when the AB sprayer was used, FDF was affected by tree height and canopy depth at either spray volume. There was lower FDF in fruit located in internal canopy positions than outside and lower FDF in lower than upper tree canopy positions in AB sprayed fruit. When the trunk shaker was used to mechanically harvest treatment trees, significantly more fruit were removed from GT-sprayed than AB-sprayed trees (Fig. 3). Although numeric differences existed between spray volumes, these were not significant.

'Valencia' trial. No significant differences were found in FDF at any tree height canopy depth or any volume when the GT sprayer was used, but differences were observed when the AB sprayer was used (data not shown). In general, mean FDF varied with greater tree height and canopy depth at the lowest and highest application volume with the GT sprayer (Fig. 4). These differences were larger and more consistent at all application volumes, however, with the AB sprayer. Sprayer type and application volume significantly affected mature fruit removal and recovery. More mature fruit were removed when CMNP was applied with the GT sprayer at 300 gal·acre^{-1} than with the AB at 200 or 100 gal·acre^{-1} (Fig. 5). There were no differences in fruit removal between the lower volume GT sprays and the higher volume AB sprays. Percentage mature fruit recovery, although lower, followed similar trends as percentage mature fruit removal (Fig. 6).

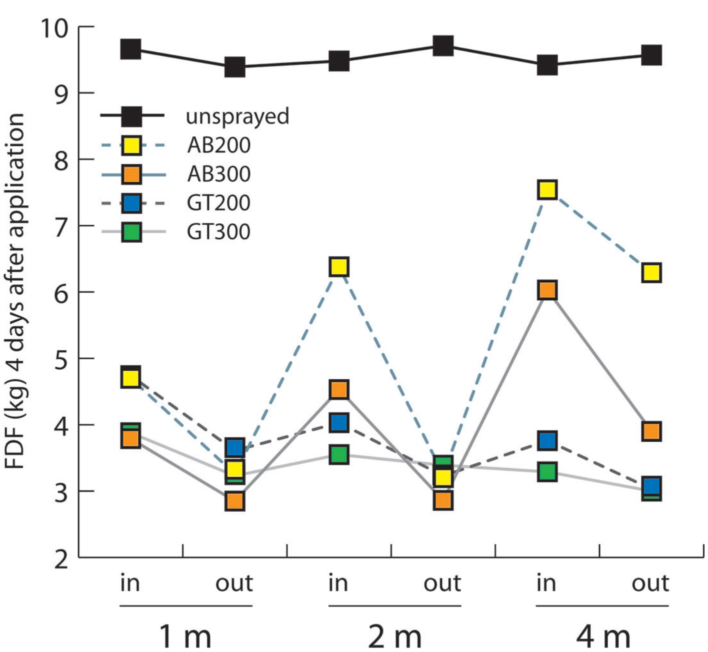

Fig. 2. Mean FDF at three tree heights and two canopy depths 4 d after application of 200 mg·L^{-1} CMNP in 'Hamlin' orange. AB, air-blast sprayer; GT, 'GreenTech' sprayer; 200, 200 gal·acre^{-1}; 300, 300 gal·acre^{-1}; control, unsprayed; in, 0.25 m from tree trunk; out, 0.25 m from canopy edge.

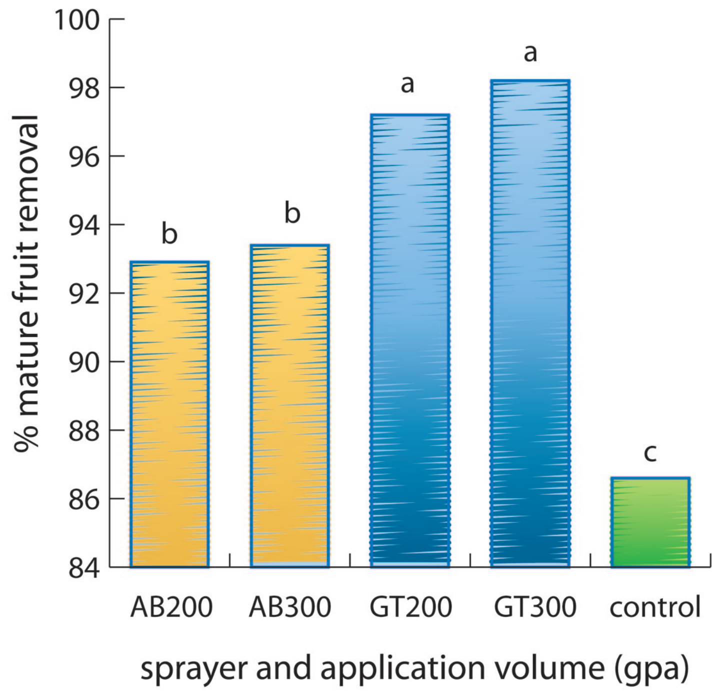

Fig. 3. Mature fruit removal percentage in 'Hamlin' orange after harvest with a trunk shaker. Trees were sprayed with 200 mg·L^{-1} CMNP 4 d prior to harvest. AB, air-blast sprayer; GT, 'GreenTech' sprayer; gpa, gal·acre^{-1}; 200, 200 gal·acre^{-1}; 300, 300 gal·acre^{-1}; control, unsprayed. Means followed by the same letter are not significantly different at the 5% probability level.

Discussion

Proper application of any plant growth regulator is required for maximum biological response. When the AB sprayer was used on either 'Hamlin' or 'Valencia' oranges, spray penetration apparently decreased as distance from nozzle discharge increased. FDF was more variable and the trunk shaker removed less mature fruit. When the GT sprayer was used, CMNP spray efficacy was improved as more uniform reduction in FDF occurred throughout the canopy. This suggested that increased spray penetration into the canopy occurred and there was better coverage of mature fruit. Importantly, better spray penetration and fruit coverage suggested that lower application volumes were sufficient to achieve high mature fruit removal percentages.

A high density of leaves in tree canopies can limit spray penetration, especially with AB sprayers. The Immokalee area was impacted by Hurricane Wilma in October 2005 so these studies were conducted in trees with reduced foliage and mature fruit. The average leaf area indices of 'Hamlin' and 'Valencia' trees in the study were 2.6 and 3.5, respectively, and these values were only slightly lower than well foliated citrus trees (Li et al., 2006). The more variable FDF readings in 'Valencia' compared to 'Hamlin' trees with both sprayer types

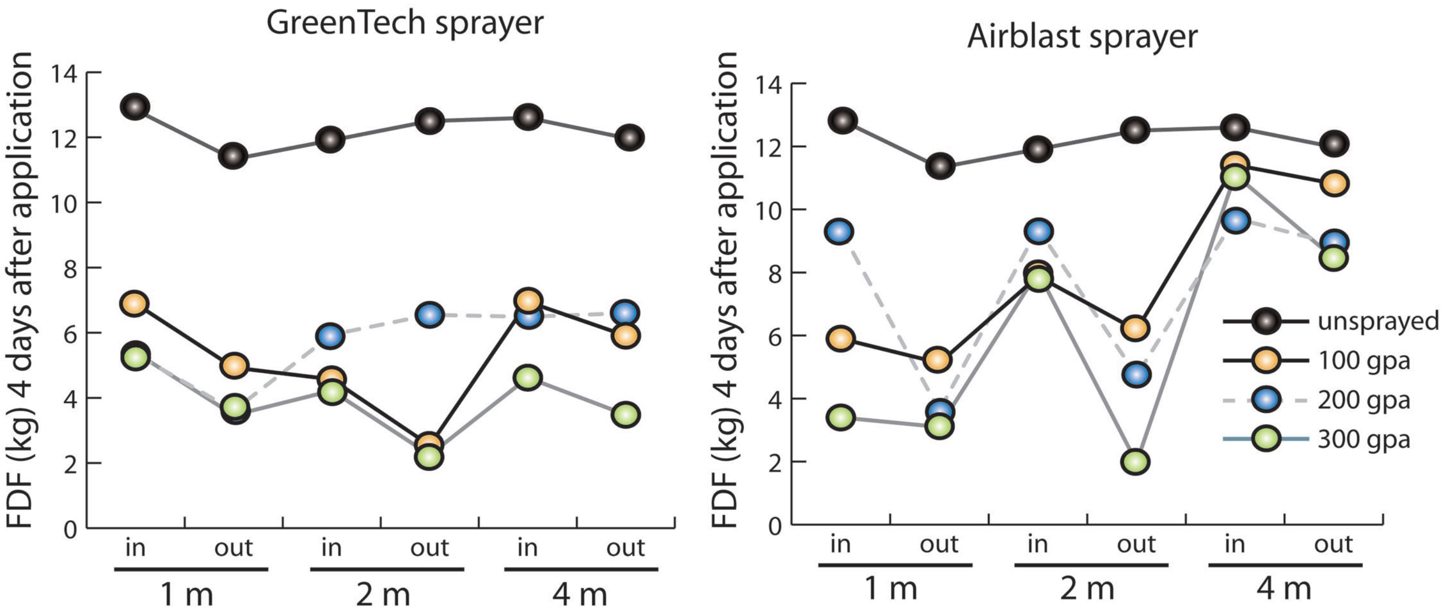

Fig. 4. Mean FDF at three tree heights and two canopy depths 4 d after application of 200 mg·L-1 CMNP in 'Valencia' orange; in, 0.25 m from tree trunk; out, 0.25 m from canopy edge.

may reflect reduced spray penetration due to differences in canopy leaf densities. Nevertheless, a 50% reduction in FDF and high fruit removal was achieved in 'Hamlin' and 'Valencia' using the GT sprayer. A 50% reduction in FDF was shown to maximize the potential for high machine fruit removal percentages (Burns et al., 2005).

In conclusion, better spray coverage can improve efficacy of abscission agents used to facilitate mechanical harvesting of sweet oranges. Additional work in 'Hamlin' and 'Valencia' trees at varying leaf densities and application volumes throughout the harvest season will be needed to assess the full potential of the GT sprayer.

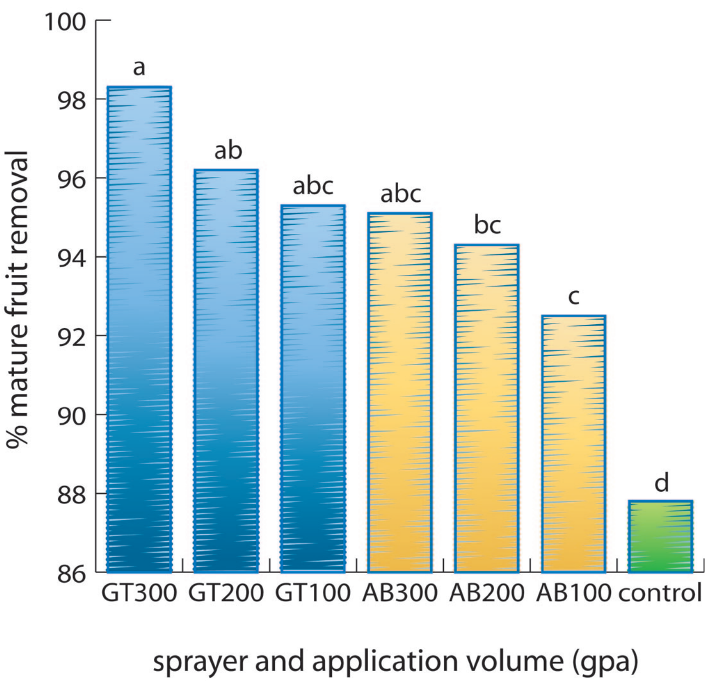

Fig. 5. Mature fruit removal percentage in 'Valencia' orange after harvest with a trunk shaker. Trees were sprayed with 200 mg·L-1 CMNP 4 d prior to harvest. AB, air-blast sprayer; GT, 'GreenTech' sprayer; gpa, gal·acre-1; 200, 200 gal·acre-1; 300, 300 gal·acre-1; control, unsprayed. Means followed by the same letter are not significantly different at the 5% probability level.

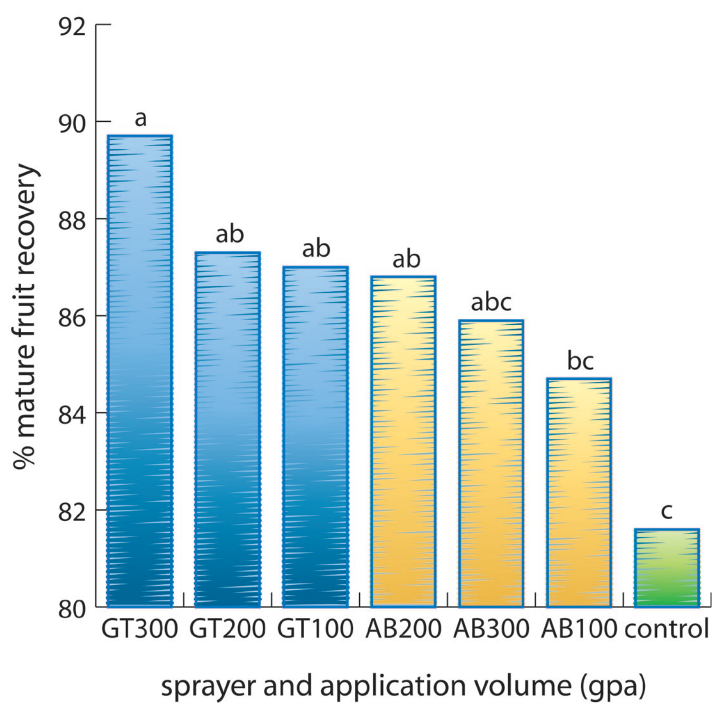

Fig. 6. Mature fruit recovery percentage in 'Valencia' orange after harvest with a trunk shaker. Trees were sprayed with 200 mg·L-1 CMNP 4 d prior to harvest. AB, air-blast sprayer; GT, 'GreenTech' sprayer; gpa, gal·acre-1; 200, 200 gal·acre-1; 300, 300 gal·acre-1; control, unsprayed. Means followed by the same letter are not significantly different at the 5% probability level.

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