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Interaction of CMNP Concentration and Canopy Shaker Setting on Fruit Removal of Sweet Orange

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Maximizing fruit removal and minimizing tree injury are two goals for mechanical harvesting of sweet oranges for the citrus juice industry. CMNP (5-chloro-3-methyl-4-nitro-1*H*-pyrazole) is an abscission agent that is in the process of being labeled as an aid to mechanical harvesting. CMNP was applied to ‘Hamlin’ groves at 0, 200, and 300 $\mathrm{mg \cdot L^{-1}}$ in a spray volume of 300 gal/acre in three trials that were conducted in mid December, early January, and late January. Dates for CMNP application were chosen when air temperatures would be near or above 15.6 °F and no rain forecast during the first 24 h after application. Four days after application, the trees were mechanically harvested with a pull-behind canopy shaker operating at frequencies of 3.0, 3.7, and 4.3 Hz and a tractor speed of 1.0 mph. The study was conducted as a randomized complete block, split plot design with canopy shaker frequency as the main plot and CMNP concentration as the split plot. There were four blocks and three trees per plot. Successful fruit loosening was demonstrated by preharvest fruit drop, which was higher for CMNP-treated trees compared with the no CMNP controls. Fruit drop was almost 35% for the 300 $\mathrm{mg \cdot L^{-1}}$ treatment in late January but was below 7% for the controls in all trials. There was a significant interaction in percent fruit removal by the canopy shaker between CMNP concentration and mechanical harvester frequency for all three dates. The difference among CMNP treatments was more evident at lower mechanical harvester settings. These results demonstrate the benefits of fruit removal by CMNP, especially at lower mechanical harvester settings.

About 13,153 ha of sweet oranges (*Citrus sinensis* [L.] Osbeck) were mechanically harvested in 2008 (Florida Department of Citrus, 2008) of the total 193,000 ha in Florida (Anonymous, 2008). Interest in mechanical harvesting sweet oranges by the commercial industry has been strong because of the low availability of high quality labor especially during the hot part of the harvesting season in May and June, the liability of hiring illegal labor, and the high costs and requirements of the H2A program. It is expected that the proportion of the acreage mechanically harvested will increase as consistently higher harvest efficiency is achieved. Harvest efficiency has varied and ranged from 50% to 98% in research studies (Whitney, 1975, 1986, 1999, 2000, 2003; Whitney et al., 2000a, 2000b; Whitney et al., 2001), and has been 70% to 85% in recent years as indicated by harvesting managers in commercial groves.

Abscission agents have promise to promote high and consistent removal rates of sweet oranges by mechanical harvesters. Of those abscission agents studied, 5-chloro-3-methyl-4-nitro-1*H*-pyrazole (CMNP) has been shown to be the most effective (Burns et al., 2005; Freeman and Sarooshi, 1976; Whitney, 1975, 1976; Whitney et al., 2000a,b; Wilson, 1973). Maximum efficacy of CMNP will require developing recommendations that include those factors that affect its activity, including concentration, coverage, temperature, and post spray precipitation events (Alferez et al., 2005; Ebel et al., 2008). Furthermore, applications of CMNP will have to be matched with oscillation frequencies of mechanical harvesting machines to maximize harvest efficiency.

One concern of commercial grove managers in recent years is the effect of mechanical harvesters on tree health and long-term productivity, even though research has shown that there are no long-term reductions in yield due to mechanical harvesters (Hedden and Coppock, 1968; Li and Syvertsen, 2005; Li et al., 2006; Whitney et al., 1986). Canopy shakers are the predominant mechanical harvesters currently used and can cause some visible injury to the canopy during use (Buker et al., 2004; Li and Syvertsen, 2004; Whitney, 2003). Canopy shakers are composed of a vertical boom with tines radiating out from the center at different heights. Each set of tines are free-floating around the boom, but are cycled by a rotor at the central pivot point [Video 1 (http://www.fshs.org/Proceedings/Password%20Protected/2009%20vol.%20122/videos/shaker.wmv)]. The frequency rate of cycling can be manually adjusted from the tractor cab, with the frequency of motion adjusted to maximize fruit removal. However, higher frequency rates are believed to cause more visible tree injury such that there is a trade-off between percentage of the crop removed and visible injury to the canopy. We theorize that CMNP will allow mechanical harvesters to be operated with lower energy inputs into the canopy, and thus cause less visible injury. This study was conducted to determine the interaction of CMNP concentration and canopy shaker frequency on the percent of the total yield removed for ‘Hamlin’ orange. To remove other effects that are known to affect CMNP efficacy, CMNP was only applied under optimal climate conditions (i.e., minimum air temperatures of 15.6 °C and no rainfall in the first 24 h after application).

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Materials and Methods

Plant material and culture. The trials were conducted in commercial groves on Flatwoods soils in southern Florida. The first study was conducted on 21-year-old 'Hamlin' on Carrizo citrange rootstock with trees spaced 3.7 × 7.8 m (CPI Ranch One Grove block P-25). The trees were 4.6 m in height when the study was conducted and skirted to 0.5 m. The soil was an Immokalee Fine Sand (siliceous, hyperthermic Arenic Alaquods). The second two trials were conducted on 17-year-old 'Hamlin' orange trees on Swingle citrumelo rootstock with trees spaced 2.4 × 6.7 m (Barron-Collier Silverstrand III grove block B-3). The trees were 4.0 m high when the study was conducted and skirted to 1.0 m. The soil was a Ft. Drum (siliceous, hyperthermic Aeric Endoaquepts) and Malabar (siliceous, hyperthermic Grossarenic Endoaqualfs) Fine Sand.

Treatments. Trees were sprayed with a multi-head air-blast sprayer (model T1000, OXBO International, Clear Lake, WI) equipped with a vertical 5.5-m boom oriented parallel to and arched over the outer part of the canopy [Video 2, Ebel et al., 2009 (http://www.fshs.org/Proceedings/Password%20Protected/2009%20vol.%20122/videos/spray.wmv)]. Each boom had six equally-spaced fan/nozzle assemblies and each fan assembly had eight Conejet no. 12 nozzles (Spraying Systems Col., Wheaton, IL) operating at 235 lb/inch^2. The tractor speed during application was 1.0 mph. CMNP (17% a.i.) was applied at 0, 200, and 300 mg·L^{-1} at 300 gal/acre with the adjuvant Activator 90 (alkylphenol ethoxylate, alcohol ethoxylate, and tall oil fatty acid; Loveland Products, Inc., Greeley, CO).

Four days after CMNP application, the trees in each trial were mechanically harvested using a pull-behind canopy shaker (model 3210; OXBO International, Clear Lake, WI). The shaker frequency rates tested were 3.0, 3.7, and 4.3 Hz. The tractor speed during harvest was 1.0 mph.

Data collected. Before harvest, fruit beneath each tree were collected and the total weight measured. After harvest, fruit on the ground were collected into bins that held approximately 450 kg of fruit and weighed. Fruit remaining in the canopy after shaking were removed by hand (gleaned) and weighed. Total yield was determined by adding the weights of the preharvest drop fruit, the fruit dropped to the ground by the mechanical harvester, and the fruit gleaned.

Temperature and rainfall were recorded with a remote weather station (HoBo Weather Logger, model H21-001; Onset Computer Corporation, Bourne, MA 02532) equipped with a 12-bit temperature smart sensor (Part no. S-TMB-M002) mounted inside a solar radiation shield (Part no. RS1) with a rain gauge smart sensor (Part no. S-RGB-M002). Both sensors were mounted on a pole 1.5–2.0 m and 6 m above ground level on the north side of each test grove. Data were recorded at 5-min intervals. Relative humidity data was recorded at 15-min intervals from the FAWN weather station located at the nearby Southwest Florida Research and Education Center near Immokalee, FL.

Statistical analysis. All trials were set up as a randomized complete-block design (RCBD) with four blocks and three adjacent trees per plot. There were at least two buffer trees between plots and a buffer row between treatment rows. Within each block was a split plot with canopy shaker setting as the main plot, and CMNP treatment as the split plot. Data were analyzed using the General Linear Models procedure of the Statistical Analysis System (SAS). When interactions were not significant, means were separated using Duncan's Multiple Range Test. Because percentage of total yield that dropped to the ground occurred before the trees were harvested, these data were analyzed as a RCBD with 12 blocks.

Results and Discussion

A label is being actively pursued for CMNP as an aid to mechanical harvesting of sweet oranges in Florida. Assuming successful registration of CMNP, it is our goal to establish protocols for its adoption by the citrus industry in Florida. Current EPA regulations, however, only allow the use of CMNP for research purposes on 10 acres of citrus per year. Thus, studies have to be limited in scope. CMNP has been studied since the early 1970s (Wilson, 1973), but there are still many questions regarding its optimum use. Besides physiological and climatic factors that affect CMNP efficacy, we also must understand how a particular amount of fruit loosening translates into improved harvester efficiency at selected harvester settings, especially frequency of the canopy shaker and tractor speed. This study was designed to apply CMNP at optimal climatic conditions (listed below) to maximize efficacy and at rates that have been shown to promote extensive fruit loosening without causing phytotoxicity (Burns et al., 2005). We chose sprayer and harvester tractor speeds to be the same (1 mph), because it is conceivable that this approach will provide the most efficient commercial scheduling mechanism between CMNP application and mechanical harvest. Using the same sprayer and harvester tractor speeds will hold constant the time elapsed between the two as the harvest progresses.

In this study, we chose to use application guiding principles to time sprays and ensure optimum conditions for maximum efficacy. Those guiding principles included spraying only if temperatures were predicted to be near or above 15.6 °C and no rain forecast for the first 24 h after application. The temperature limit was determined to be the lower limit that would provide maximum loosening (Yuan and Burns, 2004); however, the average minimum winter temperature during winter in the Flatwoods of southern Florida is normally below 15.6 °C. Thus, for the three trials conducted, the minimum temperatures during the first 24 h after spray (AS) were 52 °F (12 h AS), 56 °F (17 h AS), and 53 °F (17 h AS) for the first, second, and third trials, respectively. Choosing these dates was necessary since temperatures at night rarely were at or above 15.6 °C throughout the 2008–09 harvest season. Temperatures during application were 73 to 84 °F, 81 to 84 °F, and 77 to 82 °F for the first, second, and third trials, respectively, which is the range that promotes high rates of loosening (Yuan and Burns, 2004). Air temperature in this study can be considered to have had a minor slowing on loosening.

There were no rain events the first 24 h after spray for all three trials, the critical time period in which efficacy has been shown to be affected by rain (Kossuth et al., 1978). These studies were conducted during the dry season in Florida, characterized by occasional weather fronts that provide short durations of precipitation. Thus, precipitation is a minor concern for CMNP application during this time of year in Florida.

The optimal weather conditions led to extensive loosening as indicated by the amount of fruit drop that occurred for CMNP treated trees immediately before harvest (Table 1). Drop for the controls was below 3% for all trials and as high as 34.9% for CMNP-treated trees. Drop was higher for CMNP-treated trees in all three trials, and higher for the 300 mg·L^{-1} (20.9% and 13.2%) than the 200 mg·L^{-1} (6.0% and 6.7%) CMNP-treated trees for the first and second trial, respectively. Drop was extensive for

Table 1. Effect of CMNP concentration on fruit drop before harvest.

CMNP	Fruit drop (%)		
(mg·L^{-1})^{z}	8 Dec	5 Jan.	26 Jan.
	Main effect means		
0	0.7 c	2.0 c	2.5 b
200	6.0 b	6.7 b	30.8 a
300	20.9 a	13.2 a	34.9 a

^{z}Means within column with different letters were separated using Duncan's multiple range test ($P < 0.05$).

the last harvest date (30.8% for 200 mg·L^{-1} and 34.9% for 300 mg·L^{-1}), which was near the time the 'Hamlin' harvest season normally ends. The results demonstrate that CMNP concentration increased fruit loosening, and that the amount of loosening was higher at the end of the normal harvest season.

With a pull-behind canopy shaker system, the fruit is knocked to the ground and picked up by hand labor or a pick-up machine (Bora et al., 2006; Hedden et al., 1983; Whitney, 1999). Harvest efficiency is a function of dropped fruit plus fruit knocked down by the machine. The tractor pulling the shaker was fitted with a sweeper in front of its front tire so crushed fruit was kept at a minimum and could be ignored for determining harvest efficiency. There was a significant interaction between CMNP concentration and canopy shaker setting on the percentage of the total crop removed by drop and the canopy shakers (Table 2). Thus, similar removal rates could be found for CMNP treated trees compared to controls trees, but only at lower canopy shaker frequency. For the 5 Jan. trial, for example, 95.2% of fruit was removed by 3.7 Hz when trees were treated with 200 mg·L^{-1} of CMNP, but 4.3 Hz was required to remove 95.1% of the fruit for untreated trees. For the 26 Jan. trial, 95.8% of the fruit was removed by 3.0 Hz when trees were treated with 200 mg·L^{-1} of CMNP, but 4.3 Hz was required to remove 95.6% of the fruit for untreated trees. These results support those from an earlier study that showed that mechanical harvester settings could be lowered to remove a similar proportion of the crop when CMNP was applied (Burns et al., 2005).

In general, the total fruit removed increased with CMNP concentration and canopy shaker setting for all trial dates. At this juncture, it is not possible to set a target removal percentage due to the costs of CMNP being undetermined at this time. Although harvest managers would want to maximize harvest efficiency, the higher canopy shaker frequencies may cause more injury and thus would be less desirable to grove managers, even though the evidence to date indicates that mechanical harvesting of healthy trees does not reduce long-term productivity (Buker et al., 2004). Maintaining healthy trees in recent years has been challenging for many grove managers in Florida due the increasing pressures of the devastating greening disease (*Candidatus* Liberibacter*)* and canker (*Xanthomonas axonopodis* pv. *citri*), plus the recent high costs of fertilizers and issues surrounding water availability. The interaction of moderate to poor tree health that currently exists within the industry and the impact of mechanical harvesting on long-term productivity needs to be evaluated. Nevertheless, the harvest efficiency results from this study provide a framework from which decisions could be made for mechanical harvesting of healthy trees with respect to the CMNP concentrations, climatic conditions when it was applied, and the harvester settings as used in this study.

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Table 2. Percentage of the total yield removed and the standard error of each mean (SE) by drop and canopy shaker for each trial (date). There was a significant interaction of CMNP treatment and canopy shaker frequency for all treatments ($P < 0.05$).

CMNP applied (mg·L^{-1})	Canopy shaker frequency (Hz)	Fruit removed (%)					
		8 Dec.		5 Jan.		26 Jan.	
		Removal	SE	Removal	SE	Removal	SE
0	3.0	63.1	2.6	73.8	2.6	79.4	2.0
	3.7	81.0	0.6	85.9	2.8	83.3	2.7
	4.3	86.3	1.6	95.1	1.2	95.6	0.4
200	3.0	76.2	2.1	92.2	2.3	95.8	1.0
	3.7	82.7	0.2	95.2	1.2	98.3	0.3
	4.3	88.9	2.5	98.5	0.4	99.4	0.1
300	3.0	84.9	1.4	93.0	2.4	97.6	0.5
	3.7	91.1	1.0	97.2	1.2	98.2	0.6
	4.3	94.0	1.0	98.8	0.3	99.5	0.0

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