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Effects of Short-term Drought Stress of 'Hamlin' and 'Valencia' Trees and CMNP Application on Fruit Detachment Force, Fruit Drop, and Fruit Quality

Bob Ebel*[1], Kelly Morgan[1], Peter Newman[1], Jackie Burns[2], and Jim Syvertsen[2]

[1]*University of Florida, IFAS, Southwest Florida Research and Education Center, Immokalee, FL 34142-9515*

[2]*University of Florida, IFAS, Citrus Research and Education Center, Lake Alfred, FL 33850*

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Two studies, one on 'Hamlin' and the other on 'Valencia' trees, were conducted to determine if short-term drought stress affects efficacy of 5-chloro-3-methyl-4-nitro-1*H*-pyrazole (CMNP) for loosening fruit as an aid for mechanical harvesting. 'Hamlin' orange trees were drought stressed in late February by withholding irrigation for 5 days (control), 12 or 19 days before harvest and 'Valencia' orange trees were drought stressed in late April by withholding irrigation 0 (control), 4 or 7 days before harvest. Soil moisture, leaf conductance, transpiration and stem water potential were lower for the drought treatments compared to the controls. There was no significant interaction between drought stress and CMNP on fruit detachment force (FDF) or fruit drop. CMNP substantially decreased FDF and fruit drop; however, drought stress did not. These results indicate that drought stress from 7 to 19 days does not alter efficacy of CMNP.

Florida suffered from a one in 100-year drought in 2006–07. Rainfall in the Immokalee area over the period of Oct. 2006 to May 2007 was 3.23 inches or an 84% deficit from long-term averages. Under such dry conditions, citrus trees with irrigation zones less than 50% coverage or poor uniformity will suffer from stress even if irrigated within UF/IFAS recommendations of soil water depletion in the irrigated zone (Koo and Smajstrla, 1984). This is due to the lack of available water in the non-irrigated zone that has roots in high densities due to Florida's normally humid rainy climate (Morgan et al., 2007).

Mechanical harvesting has little impact on stem water potential of trees in well managed groves with adequate soil moisture prior to harvest (Li et al., 2006a). Likewise, long-term tree health and yield have not been shown to be adversely impacted by mechanical harvesting in well irrigated groves (Li et al., 2005, 2006b, 2006c). However, groves are not always well watered prior to harvest. This is particularly true for early harvest and drought years. In addition, some mechanical harvesting machine operators recommend letting the grove dry out prior to harvest to facilitate movement of heavy machinery in the swales. Current UF/IFAS recommendations for irrigation scheduling in the fall/winter harvest period of November to February is to allow the soil moisture level to deplete to 50% to 67% of available soil water content (Morgan et al., 2006). This soil water level has been shown to have little effect on current or future yields of well maintained groves harvested by hand (Koo and Smajstrla, 1984). No work has been done on the effect of tree water stress associated with available water depletions of 50% or greater prior to or after mechanical harvesting. Growers in the Southwest Florida production area have offered anecdotal evidence of poor tree health after mechanical harvesting under drought conditions. Thus, a lack of knowledge exists regarding the effect of irrigation scheduling prior to harvest on short-term tree health and productivity.

CMNP is being developed and is in the process of being labeled as an aid to mechanical harvesting by reducing fruit detachment force (FDF) at harvest (Burns et al., 2005, 2006a, 2006b; Whitney, 2003). Mild drought stress in many species also causes an abscission layer to form in mature fruit. Mild drought causes citrus fruit abscission during fruit set (Kriedemann and Barrs, 1981), but no reports were found that demonstrate a response of mature fruit. It is not known if CMNP would interact with drought stress to accelerate fruit abscission in citrus. The objective of this study was to determine the effects of short-term preharvest drought stress on tree water relations and efficacy of CMNP to reduce FDF. Results from this study will give citrus growers specific guidelines for irrigation management prior to harvesting and whether moderate drought stress will require adjustments in CMNP scheduling for mechanical harvesting.

Materials and Methods

Study location. The studies were conducted in commercial citrus groves near Immokalee in Collier County, southwestern Florida, during the dry season in this region. The average annual precipitation during October, November, December, January, and February is 119.3, 58.4, 48.3, 55.9, and 61.0 mm per month, respectively (Ali et al., 2000). The total of 342.9 mm (13.5 inches) of rainfall represents approximately 26% of the annual 1331 mm (52.4 in) of rainfall in southern Florida.

'Hamlin' study

Plant material and culture. The study was conducted on 288 mature 'Hamlin' orange [*Citrus sinensis* (L.) Osbeck] trees on Carrizo citrange rootstock [*C. sinensis* x *Poncirus trifoliata* (L.) Raf.] at a tree spacing of 3.35 m × 6.71 m (11 ft × 22 ft) (= 180 trees/acre; Block B-2, Oak Hammond Grove, Barron-Collier

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*Corresponding author; email: rcebel@ufl.edu

Partnership). The soil was a Holopow sand (Loamy, siliceous, hyperthermic Grossarenic Ochraqualfs).

Treatments. Trees were irrigated daily for 2 h prior to imposition of drought treatments with one microsprinkler/tree that delivered 61 $L \cdot h^{-1}$ (16 gal/h). Irrigation was terminated 24 Jan., 31 Jan., or 7 Feb., which was 19, 12, or 5 d before harvest, respectively. However, all treatments received 121 L/tree (32 gal/tree) of irrigation on 4 Feb. and there was 1.27 cm (0.5 inch) of precipitation on 7 Feb. The day before harvest, one-half of the trees in all treatments received 2 h of irrigation. Irrigation was restored on all other treatments on 14 Feb.

CMNP was applied at 200 ppm and 460 $L \cdot ha^{-1}$ (300 gal/acre), on 8 Feb. using a multi-head, air-blast sprayer (Model 1000T, OXBO International, Clear Lake, WI). The trees were sprayed between 2:00 and 3:00 PM.

Data collected. Soil and plant water status measurements were only measured on trees not treated with CMNP and that received a preharvest irrigation. Soil moisture was measured at 10 cm depth increments down to the argillic horizon at 70 cm (27 inches) using a portable capacitance probe (Diviner 2000, Sentek Sensor Technologies, Stepney, South Australia, Australia). Soil moisture measurements were taken through 5-cm (2 inch) diameter acrylonitrile butadiene styrene access tubes. Access tubes were installed in the tree row at a distance of 1 m (3.3 ft) from the tree trunk on same side of the tree as the irrigation emitter. The soil moisture sensor was calibrated for each soil series using gravimetric analysis (Morgan et al., 1999).

To estimate plant water status, leaf conductance and transpirational flux were determined from five of the most recently matured and fully sunlit leaves, near the base of 1-year-old stems, using a portable, steady-state porometer (Model LI-1600, LiCor, Lincoln, NE). Stem water potential (Ψ_{stem}) was measured using three leaves per plant, randomly selected from leaves 2.6 m from the soil surface. Leaves were initially wrapped in plastic, then aluminum foil the night before data were collected, to allow the water potential of the leaves to equilibrate with the water potential of the stem (Garnier and Berger, 1985). Wrapped leaves were severed at the petiole with a razor blade and Ψ_{stem} measured using a pressure chamber (Model 1000, PMS Instrument Co., Corvallis, OR) that was pressurized at 1 MPa/20 s using compressed air.

On 12 Feb., FDF was determined on two fruit, randomly selected per tree (12 fruit/plot), using a digital force gauge (Model Force Five, Wagner Instruments, Greenwich, CT.; Hartmond et al., 2000). FDF was determined immediately before spraying CMNP and 5 d later, when harvest would normally occur. Fruit drop was also determined by weighing all fruit under the trees.

Soluble solids and fruit water content. Twelve fruit per plot were randomly collected and soluble solids determined by hand squeezing one half of each fruit, combining the juice from each fruit and placing a drop of juice on an electronic refractometer (Abbey-3L Refractometer, Fisher Scientific, Pittsburgh, PA). The other half of fruit was weighed, dried at 60 °C for 48 h and reweighed to determine water content.

Experimental design and statistical analysis. This study was conducted as a randomized, complete-block design with 4 blocks. Soil moisture, leaf conductance, and transpiration were analyzed as a split plot design with irrigation treatment as the main plot and days before harvest as the split plot. FDF, fruit drop, fruit water content, and soluble solids content data were analyzed as a 3 (drought treatment) × 2 (irrigated or not irrigated the day before harvest) factorial, split plot with the 6 irrigation treatments as the main plots and CMNP application (with or without) as the split plot. There were 5 or 6 trees treated within each plot and means of each plot were determined before analysis. Data were analyzed using the General Linear Models (GLM) procedure of the Statistical Analysis System (SAS, SAS Institute, Inc., Cary, NC). When interactions were nonsignificant, main effect means were separated using Tukey's multiple mean procedure.

'Valencia' study

Plant material and culture. The study was conducted on 120 fully mature 'Valencia' orange (*C. sinensis*) on Carrizo citrange rootstock (*C. sinensis* x *P. trifoliata*) with a tree spacing of 3.7 m × 7.3 m (12 ft × 24 ft) (150 trees/acre; Block D-12, Silverstrand North, Barron-Collier Partnership). The soil was a Basinger fine sand (loamy, siliceous, hyperthermic, Spodic Psammaquents).

Treatments. Trees were irrigated daily for 2 h with one microsprinkler/tree that delivered 61 $L \cdot h^{-1}$ (16 gal/h) prior to treatment initiation. Irrigation was terminated 25 Apr., 28 Apr., or not terminated, which was 7, 4, or 0 d before harvest (2 May), respectively. Irrigation was restored on all other treatments on 3 May. CMNP was applied at 250 ppm and 460 $L \cdot ha^{-1}$ (300 gal/acre), on 28 Apr. using a multi-head, air-blast sprayer (Model 1000T, OXBO International, Clear Lake, WI). The trees were sprayed between 2:00 and 3:00 PM.

Data collected. Soil water status measurements were only collected on trees not treated with CMNP. Soil moisture was measured at 10-cm depth increments down to the spodic horizon at 70 cm using a portable capacitance probe, through 5-cm diameter acrylonitrile butadiene styrene access tubes. Access tubes were installed in the tree row at a distance of 1 m (3.3 ft) on each side of the center tree of each plot. Procedures for plant water status measurements were the same as in the first study. FDF was determined as in the first study. FDF was determined immediately before spraying CMNP and 4 d later on 2 May. Fruit drop was also determined by weighing all fruit under the trees.

Experimental design and statistical analysis. This study was conducted as a randomized, complete-block design with 4 blocks. Soil moisture, leaf conductance, transpiration, FDF, and fruit drop were analyzed as a 3 (drought treatment) × 2 (CMNP) factorial. There were 5 trees treated within each plot and means of each plot were determined before analysis. Data were analyzed using the GLM procedure in SAS. When interactions were nonsignificant, main effect means were separated using Tukey's multiple mean procedure.

Results and Discussion

'Hamlin' study

Impact of drought on soil moisture and plant water status. Soil moisture was highly variable among treatments possibly because of the single irrigation on 4 Feb., the rainfall on 7 Feb. or differences in root water extraction in the soil. Nonetheless, drought treatments generally had lower soil moisture contents than trees with irrigation withheld for only 5 d before harvest (Fig. 1). Leaf conductance and transpiration also variable among treatments but as with soil moisture, the 12- and 19-d drought treatments had lower values than the controls. Stem water potential demonstrated the strongest separation among treatments, dropping below –2.2 MPa 5 d before harvest for the 12- and 19-d drought treatments whereas the controls remained above –1.4 MPa. Stem water potential increased slightly principally due to approximately 1.27 cm of precipitation 4 d before harvest. By the day before harvest, leaf conductance and transpiration of the controls were higher than the 12- and 19-d before-harvest drought treatments, which were similar (Table 1). Stem water potential was highest for the controls, lowest for the 12-d before-harvest treatment and intermediate for the 19-d before-harvest treatment.

Impact of drought stress and CMNP on FDF, fruit drop, fruit water content, and soluble solids content. FDF was not affected by drought or preharvest irrigation treatments, nor were there any significant interactions between days of drought stress, preharvest irrigation, and CMNP treatment (Table 2). CMNP was effective in loosening the fruit, decreasing FDF from 51 Newtons (N) for the untreated to 15 N for the treated fruit. The loosening led to significant fruit drop for CMNP-treated trees compared to the untreated controls. There was also no effect of drought or preharvest irrigation, or the interaction of those treatments with

Table 1. ANOVA the day before normal harvest of plant water status of 'Hamlin' orange drought stressed by withholding irrigation 19, 12, or 5 (control) d before harvest.

Significance	Pr > F: Leaf conductance (mmol·m^{-2}·s^{-1})	Transpiration (mmol·m^{-2}·s^{-1})	Stem water potential (MPa)
Drought days (DD)	0.1110	0.2087	0.6034
Block	0.7152	0.9207	0.2488
Main effect means[z]			
Drought days			
5	57 A	1.42 A	–1.26 A
12	37 B	0.95 B	–1.75 B
19	36 B	0.90 B	–1.55 AB

[z]Different letters within columns indicate significant difference at $P <$ 0.05 level using Tukey's multiple mean procedure.

Table 2. ANOVA of fruit detachment force (FDF), fruit drop, and fruit water content of 'Hamlin' orange the day of harvest. Treatments consisted of trees drought stress 19, 12, or 5 d before harvest (drought days), with one-half of all drought-stressed trees irrigated the day before harvest (PI), and treated with CMNP 4 d before harvest.

Significance	Pr > F: FDF (N)	Fruit drop (kg/tree)	Fruit water content (%)
Drought days (DD)	0.1110	0.2087	0.6034
Preharvest irrigation (PI)	0.7069	0.5797	0.1262
DD × PI	0.9530	0.7760	0.0579
Block	0.0174	0.0048	0.0040
DD × PI × Block	0.5260	0.8369	0.8891
CMNP	<0.0001	<0.0001	0.0066
DD × CMNP	0.0935	0.3512	0.4563
PI × CMNP	0.9973	0.5736	0.5409
DD × PI × CMNP	0.6130	0.9331	0.9349
Main effect means[z]			
Drought days			
5	34	6.3	80.8
12	36	5.8	80.8
19	29	8.0	80.4
CMNP			
Yes	15 B	12.8 A	81.4 A
No	51 A	1.2 B	80.0 B
Preharvest irrigation			
Yes	32	---	---
No	33	---	---

[z]Different letters within columns indicate significant difference at $P <$ 0.05 level using Tukey's multiple mean procedure.

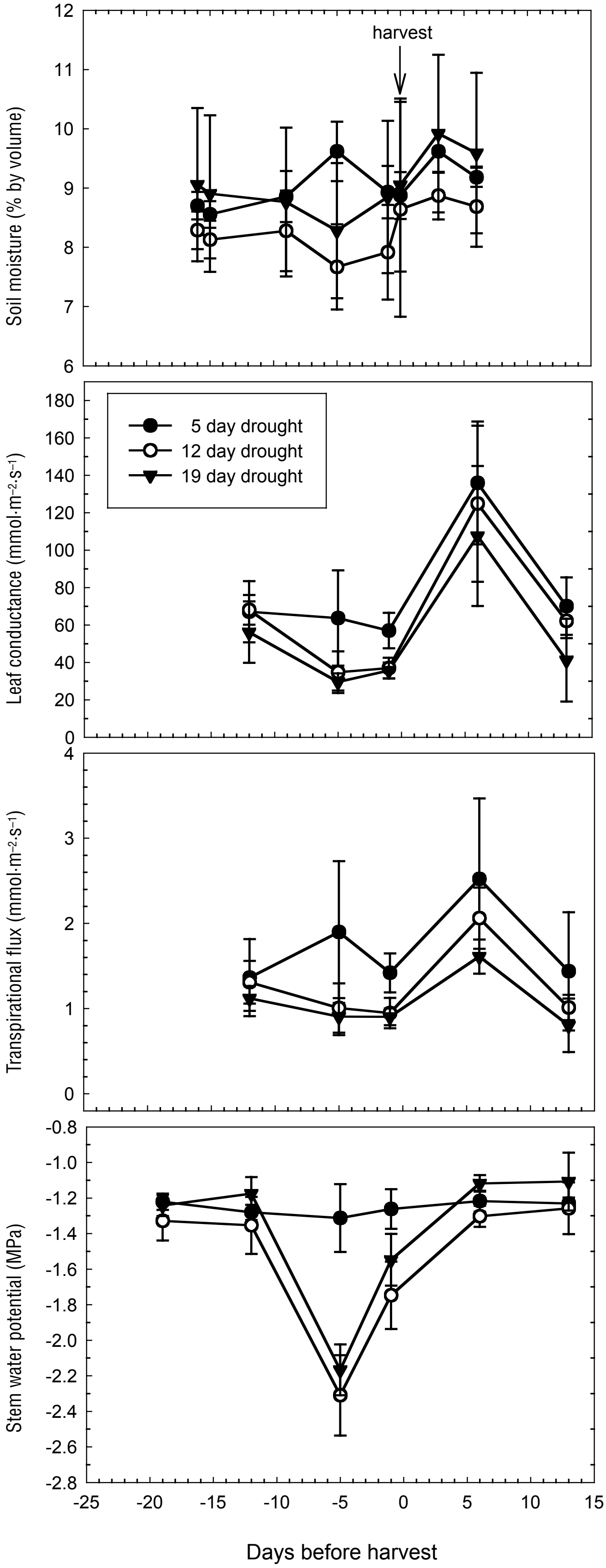

Fig. 1. Soil moisture and plant water status of 'Hamlin' orange trees drought stressed by withholding irrigation 19, 12, or 5 (control) d before harvest. The bars indicate 2× the SE of the mean.

Table 3. ANOVA of drought stress and CMNP treatments on soil moisture 2 d before harvest, and plant water status and fruit abscission the day of harvest of 'Valencia'. Drought was implemented by withholding irrigation 0 (control), 4 or 7 d before harvest (days of drought).

	Pr > F					
Significance	Soil moisture (% by volume)	Stem water potential (MPa)	Leaf conductance ($mmol \cdot m^{-2} \cdot s^{-1}$)	Transpiration ($mmol \cdot m^{-2} \cdot s^{-1}$)	Fruit detachment force (N)	Fruit drop (kg/tree)
CMNP	---[z]	0.7884	0.5549	0.1604	<0.0001	<0.0001
Days of drought (DOD)	0.3577	<0.0001	0.0559	0.0014	0.2366	0.7764
CMNP × DOD	---	0.0786	0.2011	0.2585	0.7465	0.7702
Block	0.1225	0.9968	0.5262	0.7381	0.4937	0.6383
Main effect means[y]						
Drought days						
0	8.1	–1.5 A	61 A	1.77 A	59	8.2
4	8.3	–2.0 B	31 B	1.03 B	55	8.3
7	7.3	–2.5 C	36 AB	0.85 B	50	10.2
CMNP						
Yes	---	–2.0	40	1.09	22 B	17.0 A
No	---	–2.0	56	1.35	87 A	0.9 B

[z]Not included in the model.

[y]Different letters within columns indicate significant difference at $P < 0.05$ level using Tukey's multiple mean procedure.

CMNP on fruit water content. However, there was a significant CMNP main effect with CMNP-treated fruit having slightly higher fruit water content (81.4%) than the controls (80.0%). The slightly higher water content, although small, may be significant commercially due to the higher pounds solids per acre. There was no effect of drought, preharvest irrigation or CMNP on soluble solids content (data not shown).

'Valencia' study

Impact of drought on soil moisture and plant water status. Average soil moisture content to a 70-cm depth in plots with 7 d of drought was lower (7.3% volume) compared with both 4 (8.3%) and 0 d (8.1%) of drought prior to harvest (Table 3). However, as in the 'Hamlin' study, soil moisture status was highly variable such that by 2 d before harvest, there was no significant difference among drought treatments. There was no significant interaction between days of drought and CMNP treatment for stem water potential, leaf conductance, and transpiration. Despite the high variation and apparent lack of drought treatment response on soil moisture content, there was a clear separation in stem water potential main effect means with 7 d of drought (–2.5 MPa) lower than 4 d of drought (–2.0 MPa) which was lower than the control (–1.5 MPa) the day of harvest. Leaf conductance and transpiration, where different, were also lower than the control.

Impact of drought stress and CMNP on FDF and fruit drop. There was no significant interaction between drought treatment and CMNP on FDF or fruit drop. CMNP substantially reduced FDF from 87 N for the untreated fruit to 22 N for the treated fruit. Loosening increased fruit drop from 0.9 kg/tree to 17.0 kg/tree for treated fruit.

Conclusions

The levels of drought stress imposed in this study were generally slight to moderate, based on plant water status measurements. These levels of drought stress often occur in commercial groves due to malfunctioning pumps, breaks in the irrigation lines, and from plugged lines and emitters. The lack of significant interactions between CMNP and drought stress on FDF and fruit drop indicate that these levels of drought stress will not require significant adjustments in CMNP scheduling for mechanical harvesting.

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