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MECHANICAL HARVESTING OF FLORIDA CITRUS TREES HAS LITTLE EFFECT ON LEAF WATER RELATIONS OR RETURN BLOOM

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Abstract. **Mechanical harvesting often causes visible injuries that can include shedding of leaves, flowers, and young fruit, breaking of branches, scuffing of bark, and exposure of root systems. To assess the impacts of mechanical harvesting on the health status of citrus trees, we measured removal of mature fruit, leaves, and shoots, mid-day drought stress and leaf photosynthesis of mature 'Hamlin' and 'Valencia' orange [*Citrus sinensis* (L.) Osb.] trees under restricted or normal irrigation regimes. Trees were either harvested by hand or with a linear-type trunk shaker operating at 4 Hz with 70.8 kg weight, and a 13 cm trunk displacement for various shaking durations. Shaking treatments removed >90% mature fruit without bark damage. Compared to harvesting by hand, trunk shaking removed 10% more leaf area and twigs, and occasionally caused some root exposure. Trees in dry soil developed drought stress symptoms after prolonged trunk shaking. However, no significant impairment of physiological responses by mechanical harvesting was found when trees were properly irrigated before and after harvest. Return bloom, growth, and yield of 'Hamlin' were not affected. Trunk shaking at full bloom did not affect 'Valencia' fruit set, but trunk shaking after mid-May can reduce next year's crop due to removal of immature green fruit.**

Mechanical harvesting has been evaluated and commercialized in the Florida citrus industry since 1958 (Florida Department of Citrus, 2000). Long-term growth and yield of healthy citrus trees were little affected by repeated annual mechanical harvesting for periods of 5 to 6 years (Whitney, 1995). Cost savings of mechanical harvesting relative to conventional hand harvesting can be substantial (Roka, 2004). However, the visual impact of mechanical harvesting and its perceived injury to citrus trees decreases the willingness of many growers to adopt this technology. Less than 3% of Florida's 240,000 ha of processed orange groves were mechanically harvested in the 2003 harvest season (Brown, 2005).

Visual injuries caused by mechanical harvesting can include defoliation, twig loss, removal of flowers and young fruit, exposure of roots, and occasionally the removal of some bark (Li and Syvertsen, 2004). These injuries could impact several physiological processes in mechanically harvested citrus trees. For example, removal of healthy leaves might reduce canopy water requirements and the ability of trees to produce and properly allocate food resources (photosynthetic carbohydrates). Root damage after trunk shaking could reduce root water and nutrient uptake or increase potential infection with soil-born diseases. Bark damage could increase disease pressure and alter translocation of carbohydrates. However, many studies in citrus have shown that trees can partially compensate for leaf (Syvertsen, 1994) and root losses (Eissenstat and Duncan, 1992; Hamid et al., 1988) by increasing the growth and physiological capacity of remaining tissues. Further, physiological impacts of mechanical harvesting may be quite low in early season cultivars such as 'Hamlin' where fruit are harvested during the winter season when trees are relatively inactive. On the other hand, physiological injuries could become more evident during drought stress or in late season cultivars such as 'Valencia' that were harvested when trees are actively growing in the spring. It is likely that healthy citrus trees under good management practices are better able to maintain physiological function after any potential damage from mechanical harvesting without compromising tree physiological status (Li and Syvertsen, 2005).

We initiated a long-term study in 2003 to evaluate immediate and chronic tree responses to mechanical harvesting. We proposed a systematic assessment of whole-tree physiological effects of trunk shakers that will improve our understanding about tree responses to harvest machines and environment variables (Li and Syvertsen, 2005). Our overall objective was to investigate tree physiological activity after mechanical harvesting, and to monitor return growth, tree vigor, and fruit yield of 'Hamlin' and 'Valencia' trees by: 1) determining leaf area and fruit crop load before and after mechanical harvesting, 2) assessing root growth and recovery after mechanical harvesting with trunk shakers, and 3) examining the effects of bark injury on the main trunk on tree growth, carbohydrate balance and drought stress. In this paper we report tree water status, leaf gas exchange characteristics, and return bloom after harvesting with a trunk shaker in the 2003-2004 harvest season. We hypothesized that the severity of injuries caused by a normally operating trunk shaker would not induce significant physiological stresses in well-managed citrus trees. In addition, if a tree was under environmental stresses or was actively growing, it likely would be more vulnerable to any physiological stress induced from mechanical harvesting. Injury could occur from an improperly operated machine or one that impacted trees over an excessively longer duration than that necessary to effectively remove fruit.

Materials and Methods

Several trials were initiated in 12- to 15-year-old 'Hamlin' and 'Valencia' trees sweet orange [*Citrus sinensis* (L.) Osb.] trees on Carrizo citrange [*C. sinensis* × *Poncirus trifoliata* (L.) Raf.] or Swingle citrumelo [*C. paradisi* Macf. × P. trifoliata] rootstocks in the 2003-2004 harvest season at the UF/IFAS Citrus Research and Education Center. These trials are continuing and are expected to run for at least 5 years. Dates covering key physiological periods during the harvest season were selected for harvesting tests: late November and late January for 'Hamlin' and mid March, late May, and early June for 'Valencia'. Trees were uniform and either harvested by hand or with a linear-type trunk-shaking system (FMC Corp., Lakeland, Fla.) for 10 to 30 s of shake time. The padded clamp shaker

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head was equipped with 70.8 kg of unbalanced weight and connected by a power take off to a tractor engine operating at 2100 rpm. This weight and power combination was selected to generate a shaking frequency of 4 Hz with a maximum trunk displacement of 13 cm. Mature fruit and leaf removal were calculated by the number of fruit and leaf area removed after harvest divided by total number of fruit and leaf area per tree before harvest. Leaf and stem water statuses were assessed to determine any loss of root and/or canopy function. Interactions with drought stress were studied by withholding irrigation before and after harvest. Leaf photosynthesis was assessed by net gas exchange and leaf chlorophyll fluorescence was measured with a portable photosynthesis system (LI-6200, LICOR, Inc., Lincoln, Nebr.) and a pulse-modulated fluorometer (OS-1-FL, Opti-Science, Tyngsboro, Mass.) every 2 to 3 d before and after harvest for 2 to 4 weeks. Return bloom and vegetative growth were recorded on four branches from each tree. Total nodes per branches, sprouted nodes, florescence, and new vegetative shoots were counted at bloom time. Loss of flower and young green fruit during harvest at full bloom in 'Valencia' were recorded from sample branches.

Random block design was applied in each trial. Data were subjected to analysis of variance (ANOVA). Significant differences were determined at $P \leq 0.05$ and separated by Duncan's multiple comparison tests.

Results and Discussion

Mature fruit removal and leaf loss. Hand harvesting removed 100% of the fruit. The trunk shaker removed 90% mature fruit in 10 s in early harvest 'Hamlin' and 'Valencia'. Longer shaking time increased the fruit removal slightly but there was no significant difference between 10 s or 20 s shake duration (Fig. 1a). In a late harvest, likely due to the reduction in fruit detachment force, mature fruit removal of the trunk shaker was slightly increased in both varieties. Negligible amounts of leaves were removed along with fruit when trees were harvested by hand. Ten to 15% of the leaves were removed by mechanical harvesting using 10 s shaking time (Fig. 1b). Similar to mature fruit removal, defoliation was only slightly increased by longer shaking time.

Tree water relations and drought stress. Trees harvested by the trunk shaker maintained water status similar to trees harvested by hand under most conditions during the harvest season. Even after an excessive shaking time of 30 s that was expected to cause damage to roots and trunk bark of actively growing trees, mechanically harvested trees did not show increased drought stress relative to the hand harvested trees when available soil water was high. When irrigation was withheld for 3 weeks before harvest, however, trees harvested with excessive trunk shaking (>20 s) and re-watered after harvest developed drought stress similar to that of the continuously non-irrigated trees (9 Jan. in Fig. 2). Similar to drought stress from root damage that occurs when transplanting mature trees (Castle, 1983) and root pruning studies (Moreshet et al., 1988), the shaker-induced drought stress was temporary and tree water status was quickly restored when soil water was replenished after rainfall (12 Jan. in Fig. 2). The practice of ceasing irrigation before mechanical harvesting to facilitate machine access might not be advisable if the grove has experienced any drought stress.

Leaf gas exchange and photosynthesis efficiency. Leaf photosynthesis (net Pn), stomatal conductance (g_s), transpiration (E),

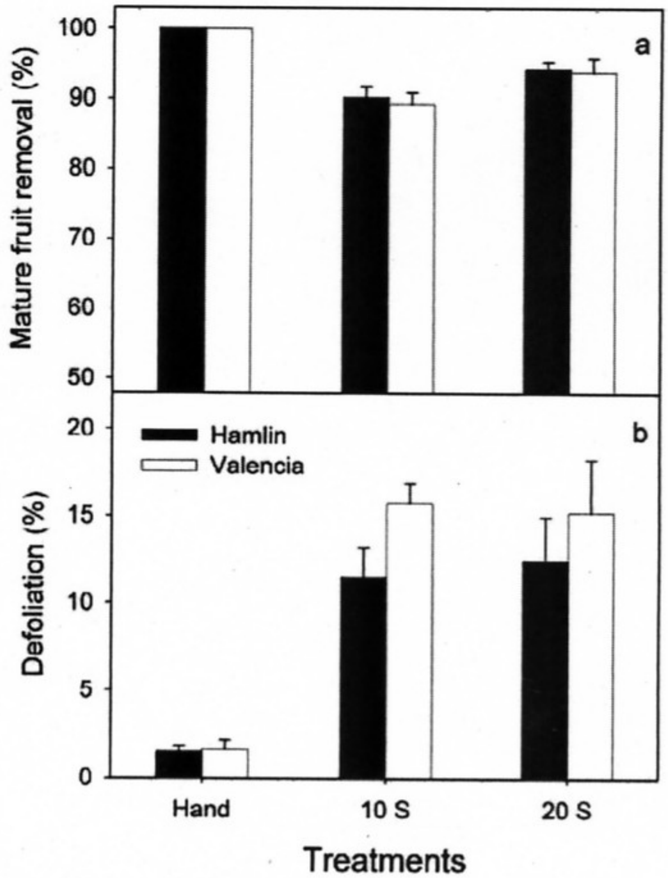

Fig. 1. a) Mature fruit removal and b) defoliation of hand and trunk-shaker harvested 'Hamlin' and 'Valencia' trees. Treatments: Hand: hand harvest; 10 S: 10 s trunk shaking; 20 S: 20 s trunk shaking. Vertical bars represent standard error.

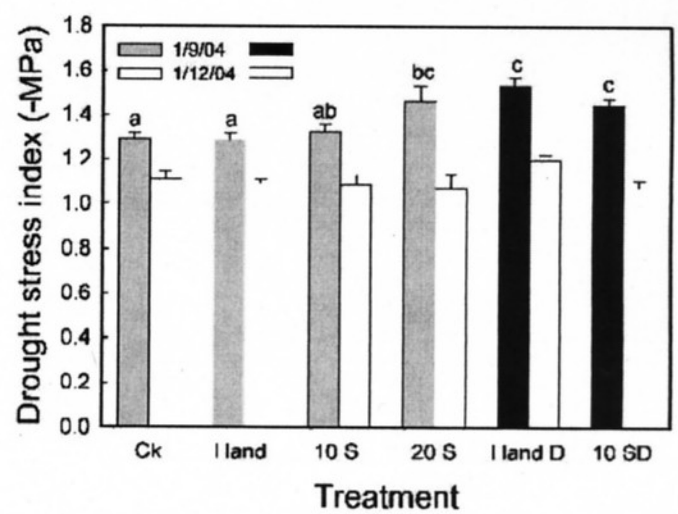

Fig. 2. Effect of mechanical harvesting and irrigation on tree water status in 'Hamlin' citrus trees. Treatments: Ck: trees were not harvested; Hand: hand harvest; 10 S: 10 s trunk shaking; 20S: 2 0 s trunk shaking; Hand D: hand harvest and postharvest drought stress; 10 SD: 10 s trunk shaking and postharvest drought stress. Trees were harvested on 7 Jan. 2004. Trees did not receive water 3 weeks prior to harvest. Trees other than postharvest drought treatments received irrigation on 8 Jan. Rainfall (8.6 mm) was recorded after 9 Jan. measurements. Colored bars represent water-stressed treatments, whereas white bars represent treatments after water-stress was relieved by rainfall. Vertical lines represent standard error.

Table 1. The effect of harvesting and postharvest drought stress on net photosynthesis (Pn, $\mu mol \cdot m^{-2} \cdot s^{-1}$), stomatal conductance (g_s, $mol \cdot m^{-2} \cdot s^{-1}$), transpiration (E, $mmol.m^{-2} \cdot s^{-1}$), water use efficiency (WEU, $\mu mol\ CO_2 \cdot mmol^{-1}\ H_2O$), and chlorophyll fluorescence (Chl. fluor.) in leaves on 'Hamlin' citrus trees.

Treatments[z]	Net Pn	g_s	E	WUE	Chl. fluor.
Ck	6.00 a	0.077	1.58	3.71 a	0.78
Hand	5.01 ab	0.069	1.51	3.14 ab	0.77
10 S	4.98 ab	0.077	1.44	3.18 ab	0.77
20 S	3.60 b	0.060	1.29	2.57 b	0.76
Hand D	3.95 b	0.056	1.40	2.66 b	0.75
10 SD	4.30 b	0.062	1.47	2.82 b	0.74

[z]Treatments: Ck: trees were not harvested; Hand: hand harvest; 10 S: 10 s trunk shaking; 20 S: 20 s trunk shaking; Hand D: hand harvest and postharvest drought stress; 10 SD: 10 s trunk shaking and postharvest drought stress. Letters within columns indicate treatment mean separation by Duncan's multiple comparison test at $P \leq 0.05$.

leaf water use efficiency (WEU), and leaf chlorophyll fluorescence were not affected by defoliation or putative root injuries caused by the trunk shaker (Table 1). The low leaf photosynthesis after harvest in 'Hamlin' trials appeared to be directly related to low wintertime temperature conditions after harvest dates. Partial defoliation can increase leaf photosynthetic ability in remaining leaves of citrus seedlings (Syvertsen, 1994). However, the defoliation effect on leaf photosynthesis was less pronounced in mature trees. The low level of defoliation caused by mechanical harvesting in this study did not cause any apparent photosynthetic compensation in light-exposed leaves. In addition, citrus trees can have high canopy densities with leaf area per ground surface area from 3 to 11 (Jahn, 1979). Thus, the defoliation after mechanical harvesting was not expected to remarkably reduce the ability of the citrus tree canopy to capture sunlight.

Return growth, yield, and harvest Valencia after bloom. There was no difference in return growth in 2004 between trees harvested by hand or by trunk shaker as evaluated from percentage return bloom, bloom type (leafless or leafy florescence), and vegetative flushes (data not shown). When we harvested 'Valencia' at full bloom, trees shed many flower petals during trunk shaking but trunk shaker and hand harvest removed similar amounts of flowers and young fruit (<12% in 2004). The final fruit set after harvest was not affected by trunk shaking. However, a number of young green fruit were removed along with mature fruit when 'Valencia' trees were harvested with the trunk shaker after mid May. In 2004, we observed that >200 green fruit per tree could be removed by the same trunk shaker in early June. This would be expected to reduce yield of the next crop.

The results indicated that healthy, well-managed citrus trees can tolerate low levels of defoliation as well as any potential root and bark injury caused by mechanical harvesting with a trunk shaker without developing physiological stress. Trees that were shaken for an excessive duration of >20 s might have had more severe root damage and thus developed temporary drought stress when soil moisture was relatively low. This drought stress can be avoided by limiting shaking time to <10 s or with proper grove irrigation. Mechanically harvesting during bloom in 'Valencia' did not diminish fruit set. These results indicated that there was no immediate physiological effect of mechanical harvesting on tree health and vigor in either 'Hamlin' or 'Valencia' orange trees. However, mechanical harvesting appears to be problematic in late harvest 'Valencia' due to the potential loss of immature fruit from the next crop. The availability of an abscission compound for late season 'Valencia' harvests will decrease the mechanical force necessary to remove mature fruit and reduce immature fruit loss thereby minimizing any negative impact of mechanical harvesting on next season's yield.

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