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Improved Irrigation Increases Water Use Efficiency and Tree Growth on Growers' Citrus Groves

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The agriculture industry consumes the highest freshwater withdrawals and the Florida citrus industry uses about 30% of irrigated cropland acreage. Availability of water is one of the most significant restrictions on crop production. Therefore, the development of new management approaches to improve irrigation efficiency is an urgent need. The objective of this study was to identify commercial citrus groves, investigate the impact of irrigation rates based on crop water requirements, and to determine the best water use efficiency techniques at selected irrigation rates and tree densities. The study was conducted at a commercial citrus grove near Immokalee, Florida, on nine-year-old sweet orange (*Citrus sinensis*) trees. The experiment consisted of three tree densities (145, 196, and 373 trees per acre) and three irrigation rates: 50%, 78%, or 100% of the reference evapotranspiration (ETo). In reaction to the different irrigation rates, soil moisture on the top three soil layers (0–6, 6–12, and 12–18 inches) remained uniformly distributed when the tree received 78% irrigation rate on the highest tree density (373 trees/acre). Meanwhile, the highest tree density which received the lowest irrigation (50%) rate had the greatest root length density (RLD), tree root volume (TRV), and average root branching angle (ABA) indicating that lower irrigation promoted more root growth than the highest irrigation rates. Root branching was significantly higher on trees that received the lowest irrigation volume than the highest which may be an indication for the highest resource utilization efficiency. The moderate irrigation rate and tree densities had the highest RLD, TRV, but similar ABA. The highest tree canopy volume occurred at the lowest tree density, yet no significant variation was detected because of the irrigation rates.

The agriculture industry consumes the highest water volume and accounts for 70% of worldwide freshwater withdrawals (Mbabazi et al. 2017; United Nations, 2015). The Florida citrus industry accounts for the greatest share (30%) of irrigated cropland acreage (The Balmoral Group, 2018). Availability of water is one of the most significant restrictions on crop production (Graham et al. 2013). Due to the increasing demand for drinking and industrial usages, the percentage of agricultural water is predicted to decrease (United Nations, 2015). The future higher crop production requirements to feed an increasing population with decreased water availability represents a significant challenge to researchers in crop production (Kadyampakeni et al., 2014). In citrus, the lack of water at any stage of the growth decreases the yield and fruit quality. In contrast, higher irrigation amounts could result in substantial loss of nutrients and herbicides from the citrus root zone through deep percolation and surface runoff, which can cause polluted water resources in the surrounding environment include lakes, rivers, and groundwater (United Nations, 2015). Therefore, developing better water management is urgently needed. Typical methods for monitoring crop water stress include measurements of soil water content, plant growth, root development, and meteorological variables including evapotranspiration (ETo) and precipitation. The objectives of this study were: 1) identify commercial citrus groves with tree densities ranging from 1145-370 trees per acre; 2) investigate the impact of irrigation rates as a function of evapotranspiration (ET) on each tee density level and 3) determine water use and gas exchange rate of tree at selected irrigation rates.

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Materials and Methods

Site description and experimental design

The study was conducted at Ranch One Corporation, a commercial citrus producer. The site had sandy soils consisting more than 90% sand, located in Southwestern Florida near Immokalee, Florida (lat. 26.50° N, long. 81.27° W) during 2019–2022. The grove was planted during 2010 with 'Valencia' (Citrus sinensis) trees grafted on the Carrizo, US-812, and US-897 citrus rootstock with planting densities of 163, 283, and 373 trees per acre.The experiment was designed as a split-plot design on three blocks of selected densities and irrigation patterns.

The experimental area consists of three-1000-foot-long beds with drainage swales on each side. The three beds were divided into 42 plots of three trees densities and were replicated six times and arranged as randomized complete-block design. Trees spacing were: a) 8 feet between trees and 14.6 ft between rows (373 trees/acre); b) 12 feet between trees and 22.2 ft between rows (145 trees/acre); and c) 6.8 feet between trees and 22.6 feet between rows (196 trees /acre). All trees were planted in Malabar fine sand soil (loamy, siliceous, active, hyperthermic Grossarenic Endoaqualfs).

TREATMENTS AND DATA COLLECTION. Trees received irrigation with the micro-jet sprinkler method, with one emitter per tree (lower density) or one emitter per two trees (higher density) and different flow rate to meet the proposed irrigation treatment per tree as following: 8.3 gallons/h, 12.8 gallons/h, and 16.5 gallons/h emitter for 50% ETo, 78% ETo, and 100% ETo emitters, respectively. Irrigation emitters were placed one foot away from each tree trunk at the lower density rate or in the middle between two trees at higher planting rates.

Six soil moisture devices (SDI-12 Drill and Drop Probe; Sentek, Stepney, South Australia) were installed per tree and used for each irrigation rate at the three densities to record the soil moisture configuration along with the three soil profiles (Ayankojo et al. 2020). The soil moisture sensors use the capacitance method of estimating volumetric water content and were used to determine irrigation effects on the soil moisture status. Root growth pattern data were collected using minirhizotron tubes installed in the soil where about 2-ft long acrylic tubes were inserted 1 ft from the tree at 45° to the ground. Root images were captured using a CI-600 In-Situ Root Imager camera (CID-Bioscience, Camas, WA), processed, and converted these images into a quantitative variables using Root Snap CI-690 software (version 1.3.2.25, CID-Bioscience, Camas, WA, USA). The tree canopy volume of a tree was determined by measuring the average diameter width of each tree in the east-west and north-south and canopy height:

$$TCV = \frac{4}{3} \times \pi \times r^2 \times \left(\frac{h}{2}\right)$$

where: TCV = Tree canopy volume (ft^3); r = mean canopy radius (ft^2); and h = canopy height (ft).

Results and Discussion

Soil moisture

Two-row trees (145 trees/acre). The soil moisture extended as far as 18 in and most of which eventually accumulated in the lowest soil layers when the grower's preferred irrigation rate (100%) was applied under the highest irrigation rate (Fig. 1). This also had implications on the root growth of the trees. When trees received the lower irrigation (78%), the soil moisture had uniform distribution across the three soil layers during the entire season.

Two rows (196 trees /acre). The soil moisture under the full irrigation had about 200% more water in the lower soil layers (12 and 18 inches) during the spring season (January – mid-April). The distribution of the soil moisture was higher during summer than the spring season making a continuous soil moisture pattern across the three layers in the full irrigation (Fig. 2). The pattern of soil moisture and the distribution across the three layers were uniform when the tree received lower irrigation (78%) as compared with the grower full irrigation (100%). Irrigation water accumulation at the lowest soil profile was considered wastewater beyond the reach of the root zone. The tree orientation in the moderate tree density had less penetration of sunlight and wind gust that enabled the soil moisture to remain moist. This had also an impact on the RLD, TRV, and ABA of the root remains the lowest as compared to the other tree densities and irrigation.

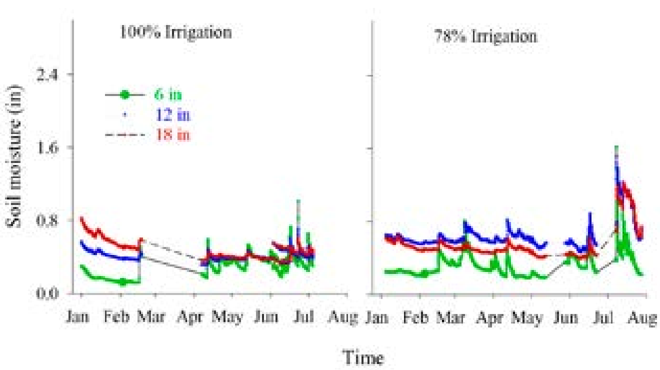

Fig. 1. Soil moisture of three soil layers (0–6, 6–12, and 12–18 in) under two-rows'Valencia' (*Citrus sinensis*) trees with a single sprinkler per tree and tree density (145 trees /acre) at Ranch One Corporation, near Immokalee, FL during 2021.

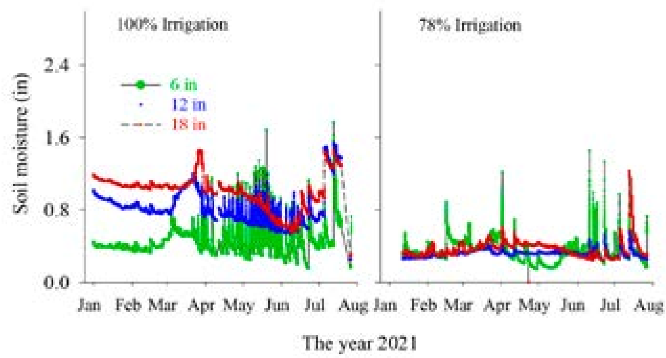

Fig. 2. Soil moisture of three soil layers (0-6, 6-12, and 12-18 in) under a two-row 'Valencia' (*Citrus sinensis*) tree with a single sprinkler per two trees and tree density (196 trees /acre) at Ranch One Corporation during 2021.

Three-row trees (373 trees /acre). The soil moisture on the top three soil layers (0–6, 6–12, and 12–18 inches) remained uniformly distributed when the tree receive 78% of the grower rate (Fig. 3). The higher and lower rates had either over moisture or uneven moisture distribution within the active root zone soil layer (0-18 inches). Higher accumulation of water was observed under the two extreme irrigations. The sharp increase in the soil moisture in all the graphs in July and August was the result of the commencement of the rainy summer season. The highest increase in the soil moisture during this season on the lowest soil depth was because of the increase in the soil water table.

Root Growth Pattern

The lowest tree density (145 trees /acre) showed the highest RLD, TRV, but similar ABA when trees received the lower irrigation (78%) than the highest irrigation (100%) rate (Fig. 4 and Table 1). Similarly, the moderate tree density (196 trees /acre)

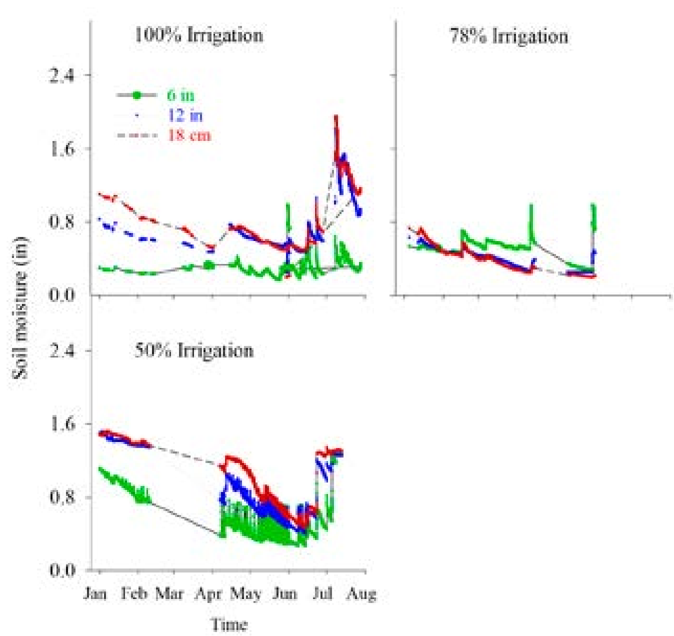

Fig. 3. Soil moisture of three soil layers (0-6, 6-12, and 12-18 in) under three-row'Valencia' (*Citrus sinensis*) trees with a single sprinkler per tree and tree density (372 trees /acre) at Ranch One Corporation, near Immokalee, Florida during 2021.

Table 1. Effect of plant density and irrigation volume on citrus 'Valencia' (*Citrus sinensis*) tree roots: tree root volume (TRV), and average root branching angle (ABA) during 2021 growing season.

	50% (ETo)		78% (ETo)		100% (ETo)	
Treatments	TRV (in^3)	ABA (°)	TRV (in^3)	ABA (°)	TRV (in^3)	ABA (°)
Two rows[z]	–[y]	–	12.5	55.3	4.9	52.4
Two rows[x]	–	–	9.8	53.9	3.8	0
Three rows[w]	3.1	62.2	2.0	34.3	0.78	0

[z]Two-row tree with a single sprinkler per tree and tree density (145 trees /acre).
[y]No data available for 50% ETo irrigation for these tree densities.
[x]Two-row trees with a single sprinkler per two trees and tree density (196 trees /acre).
[x]Three-row trees with a single sprinkler per tree and tree density (372 trees /acre).

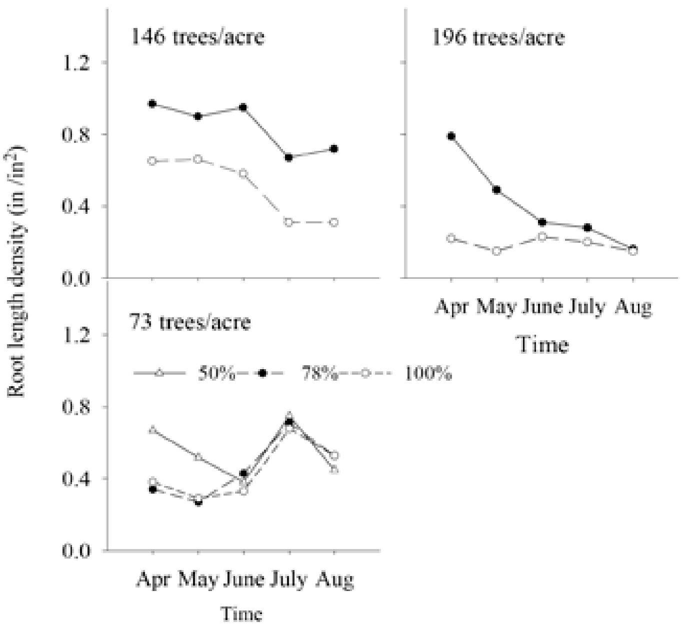

Fig. 4. Root length density under different 'Valencia' (*Citrus sinensis*) tree densities at Ranch One Corporation, near Immokalee, FL during 2021.

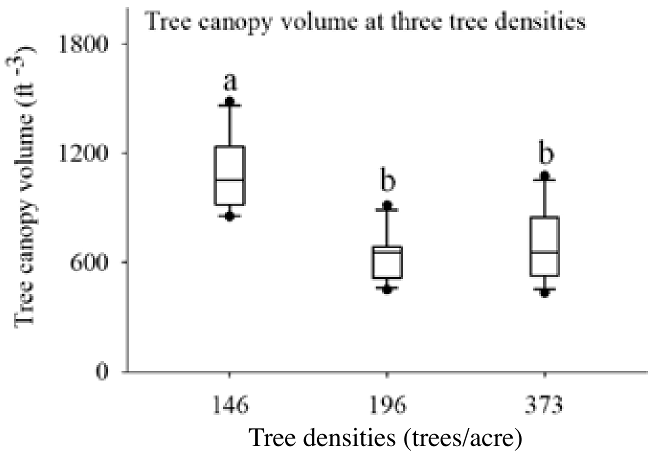

Fig. 5. Tree canopy volume of 'Valencia' (*Citrus sinensis*) under three planting densities.

showed a significant RLD, TRV, and ABA when trees received the lower irrigation (78%) than the highest irrigation. Therefore, under the lowest irrigation, root growth was greater than the highest irrigation that resulted in increased water uptake efficiency. Trees at the highest density (373 trees /acre) and the lowest irrigation (50%) had the greatest RLD, TRV, and ABA indicating that lower irrigation rates promotes root growth. Root branching was significantly higher on trees receiving the lowest irrigation volume than the highest (100%) which is an indication for the highest resource utilization.

Tree Canopy Volume

The tree canopy volume was significantly higher when the trees had wider spaces to grow than high-density tree arrangements. (Fig. 5)

Conclusion

The current results indicated that the moderate irrigation rate (78%) and moderate tree density (196 trees /acre) showed the highest water use efficiency and its impact on root developments and tree growth. The pattern of soil moisture across the three soil layers was uniform when the tree received moderate irrigation (78%) as compared with the grower's preferred full irrigation (100%). However, the increase in the soil moisture in all irrigation rates and tree densities in summer (July and August) because of the increase in soil water, suggesting water-saving strategies need to be applied or the entire halt of irrigation during the rainy season. Meanwhile, the highest tree density which received the lowest irrigation (50%) rate had the greatest RLD, TRV, and ABA indicating that lower irrigation promotes more root growth, hence, the highest water use efficiency. Generally, reduced irrigation promoted the highest RLD, TRV, and ABA for increased water uptake and resource optimization.

Literature Cited

Ayankojo, I.T., K.T. Morgan, D.M. Kadyampakeni, and G.D. Liu. 2020. Tomato growth, yield and root development, soil nitrogen and water distribution as affected by nitrogen and irrigation rates on a Florida sandy soil. HortScience 55(11):1744–55. https://doi.org/10.21273/HORTSCI15177-20

Graham, J.H., E.G. Johnson, T.R. Gottwald and M.S. Irey. 2013. Presymptomatic fibrous root decline in citrus trees caused by huanglongbing and potential interaction with *Phytophthora* spp. Plant Disease 97(9):1195–99. https://doi.org/10.1094/PDIS-01-13-0024-RE

Kadyampakeni, D.M., K.T. Morgan, A.W. Schumann and P. Nkedi-Kizza. 2014. Effect of irrigation pattern and timing on root density of young citrus trees infected with huanglongbing disease. HortTechnology 24(2):209–21. https://doi.org/10.21273/HORTTECH.24.2.209

Mbabazi, D., K.W. Migliaccio, J.H. Crane, C. Fraisse, L. Zotarelli, K.T. Morgan and N. Kiggundu. 2017. An irrigation schedule testing model for optimization of the Smartirrigation avocado app. Agricultural Water Management 179:390–400. https://doi.org/10.1016/j.agwat.2016.09.006

McCutchan, H. and K.A. Shackel. 2019. Stem-water potential as a sensitive indicator of water stress in prune trees (*Prunus domestica* L. Cv. French). J. Amer. Soc. Hort. Sci. 117(4):607–11. https://doi.org/10.21273/JASHS.117.4.607

Florida Department of Agriculture and Consumer Services. 2018. Florida statewide agricultural irrigation demand estimated agricultural water demand, 2016–2040. Florida Dept. of Agriculture and Consumer Services, Tallassee, FL.

United Nations. 2015. WWAP (United Nations World Water Assessment Programme). 2015. The United Nations World Water Development Report 2015: Water for a Sustainable World. UNESCO, Paris, France.