

In Situ Soil-water Characteristic Curves for Tropical Fruit Orchards in Trenched Calcareous Soil

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SUMMARY. Most tropical fruit trees in southern Florida are grown in calcareous gravelly soil that is mechanically trenched to a depth of about 50 cm (about 20 inches). Fruit trees are often planted at the intersections of perpendicular trenches to provide space for root development. Tree root systems are concentrated in the top 10 to 20 cm (about 4 to 8 inches) of soil. Extreme soil rockiness has made it difficult to obtain consistent and reliable measurements of soil water status and to collect soil samples for constructing soil-water characteristic curves in the laboratory. Multisensor capacitance probes and

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low-tension [0 to 40 kPa (centibars) (0 to 5.8 lb/inch²)] tensiometers were installed adjacent to star fruit (*Averrhoa carambola* L.) and avocado (*Persea americana* Mill.) trees in trenches to simultaneously measure volumetric soil water content and soil matric potential in situ. Capacitance probes consisted of four sensors centered at depths of 10, 20, 30, and 50 cm (3.9, 7.9, 11.8, and 19.7 inches). Tensiometers were installed at 10- and 30-cm depths, adjacent to the 10- and 30-cm deep capacitance sensors. Measurements obtained with both instruments were used to generate in situ soil-water characteristic curves. Rock fragments were more abundant at 30 cm than at 10 cm (71% to 73% versus 26% to 38% of bulk soil volume, respectively) soil depth, which limited the precision of tensiometers at the greater depth. In situ soil water characteristic curves for the 10-cm soil depth can be used to determine parameters needed for irrigation scheduling by techniques such as the water budget method.

Most tropical fruit orchards in southern Florida are established in very gravelly calcareous soil classified as loamy-skeletal, carbonatic, hyperthermic, Lithic Udorthents (Noble et al., 1996). This soil, commonly referred to as Krome very gravelly soil, is extremely hard in its natural state and tree roots cannot easily penetrate it. For commercial fruit tree cultivation, orchards are often established in mechanically excavated, perpendicular trenches about 50 to 75 cm wide (about 20 to 30 inches) and 50 cm deep. Trees are planted in the intersections of trenches to increase the space available for root growth (Colburn and Goldweber, 1961). The soil within these trenches has abundant rock fragments and, consequently, poor nutrient- and water-holding capacity.

Information on the water-holding capacity of soils is important for irrigation management decisions. Accurate measurement of soil water status in tropical fruit orchards established in trenches has been difficult due to the extreme rockiness of the mechanically ground soil filling the trenches. Soil-water characteristic curves expressing the relationship between soil water content and soil matric potential (capillary tension) are commonly used to obtain information

about the water-holding capacity of soils. A pressure-plate apparatus is often used to generate these curves under laboratory conditions using soil samples collected in the field (Klute, 1986). Mechanical disturbance of the soil samples can result in inaccurate relationships between soil water content and soil matric potential (Parchomchuk et al., 1997). Due to the rockiness of Krome very gravelly soil, it has not been possible to collect undisturbed soil samples from trenches to generate soil-water characteristic curves using typical laboratory measuring devices (T. Obreza, personal communication).

In recent years, multi-sensor capacitance probes (EnviroSCAN, Sentek PTY Ltd., Kent Town, Australia) have been used to measure volumetric soil water content in southern Florida tropical fruit orchards established in trenched calcareous soil (Núñez-Elisea et al., 2000; Zekri et al., 1999). The EnviroSCAN probe allows continuous and precise monitoring of soil water content at 10-cm depth intervals within and below the active root system, providing critical information for irrigation management decisions. Similar electronic devices used to measure volumetric soil water content include time domain reflectometry (TDR) probes (Nadler et al., 1991; Parchomchuk et al., 1997).

Tensiometers have gained interest as irrigation management tools in calcareous gravelly soil due to their low cost and ease of installation, particularly in vegetable fields. Tensiometers placed at a 10-cm depth were used to monitor soil water status in tomato (*Lycopersicon esculentum* Mill.) fields in Homestead, Fla., with satisfactory results (Li et al., 1998). In contrast to fruit orchards established in trenches, the continuous use of agricultural machinery in vegetable fields homogenizes soil particles in the top 30 cm of the soil profile and likely reduces rock fragment size year after year. The soil surface in tropical fruit orchards accumulates organic debris (leaves, twigs, etc.) from tree canopies that is not incorporated into deeper soil layers.

Simultaneous measurements of soil water content and soil matric potential in the field can be used to generate soil-water characteristic curves with minimal disturbance to the soil. For example, in situ soil-water charac-

teristic curves were produced for a sandy loam soil using a time domain reflectometry (TDR) probe placed at 40-cm (15.7-inch) depth and a tensiometer placed at 30-cm depth, and making periodic measurements as the soil dried between irrigations (Parchomchuk et al., 1997). Our objective was to generate in situ soil-water characteristic curves for tropical fruit orchards established in trenched calcareous soil using capacitance sensors and low-tension tensiometers placed at equivalent depths.

Materials and methods

ORCHARD SITES. The study was conducted in commercial 'Donnie' avocado and 'Arkin' star fruit orchards in Homestead, Fla. Avocado trees were 5 years old and star fruit trees were 12 years old. Both orchards were established in Krome very gravelly loam soil, and the trees were planted at the intersection of perpendicular trenches. Trees were managed according to recommended practices for fertilizer use, pruning, and disease and pest control. Orchards were irrigated with solid-set, high volume under-tree sprinklers.

SOIL WATER STATUS. Two sampling sites were used in each orchard to simultaneously monitor volumetric soil water content and soil water tension under tree canopies. Each site consisted of a Sentek EnviroSCAN multi-sensor capacitance probe and two tensiometers installed at 10- and 30-cm depths. These depths were chosen based on our findings that fruit tree root systems growing in trenches in calcareous soil are located in the top 30 cm of soil (Zekri et al., 1999), with most roots concentrated in the top 10-cm soil layer (Núñez-Elisea et al., 2000). Tensiometers were located 25 to 30 cm (about 10 to 12 inches) from the edge of the probe, beyond the 10-cm ring probed by the capacitance sensors to measure soil water content.

Each probe consisted of four, 10-cm tall capacitance sensors centered at 10-, 20-, 30-, and 50-cm depths. Probes measured volumetric soil water content at 15-min intervals. Data were recorded with a solar-powered datalogger (EnviroSCAN model RT6) and downloaded to a portable computer. Volumetric soil water content at each sensor was expressed as millimeters of water in the corresponding 10-cm soil layer, which is equivalent to percent soil water content for that soil layer.

Technical specifications of sensor and probe construction were described by Paltineanu and Starr (1997).

Probes were encased in rigid polyvinyl chloride (PVC) access tubes, which were inserted in holes augered with a portable motorized drill rig. Slurry prepared with finely ground calcareous rock, cement, and water (about 2:1:1 by volume) was applied to the bottom of each hole before inserting the probe access tubes. This procedure was done to fill the air space [2 to 3 mm (0.08 to 0.12 inches)] between the outer wall of the access tube and the wall of the augered hole, ensuring good contact of the probe sensors with surrounding soil.

Soil matric potential was measured with low-tension tensiometers (model LT; Irrometer Co., Inc., Riverside, Calif.), which are designed for

coarse-textured soils with low water-holding capacities. These tensiometers measure capillary tension in the range of 0 to 40 kPa, offering a finer resolution near saturation level. Tensiometers were calibrated using a portable pressure chamber (Smajstrla and Pitts, 1997) before they were installed in the field. Holes for tensiometers were made with a solid metal bar [23 mm (0.7 inches) in diameter] inserted into the ground with a sledgehammer. About 50 mL (1.7 fl oz) of slurry prepared with sieved soil [particles <1 mm (0.04 inches)] were poured into each hole before inserting the tensiometers in the ground to ensure good contact between the tensiometer ceramic cup and surrounding soil.

IN SITU SOIL-WATER CHARACTERISTIC CURVES. Tensiometer readings were collected on at least 45 occasions in each

of the four probe/tensiometer sets during an 8-week period from March to May 1999. For each orchard and soil depth, the soil water content value corresponding to each tensiometer reading was obtained from the database generated for each capacitance sensor. Scatter plots relating soil water (capillary) tension and volumetric soil water content were produced for each soil depth in each orchard using these paired water content-water tension values. Soil water tension values that had multiple observations of soil water content were selected from the scatter plots. The soil water content values common to a soil water tension value were averaged and the resulting data points were connected to generate the in situ soil-water characteristic curves.

Probe/tensiometer sets ($n = 2$) were installed at the same depths in different locations within the same orchards in October 1999, for a period of 3 weeks, and the same soil water data were collected.

SOIL PHYSICAL PROPERTIES. Soil bulk density and the fraction (percentage) of bulk soil volume for particles less than 2 mm (0.08 inches) in diameter and particles equal to or larger than 2 mm in diameter (rock fragments) were calculated for the 10-cm and 30-cm soil depths in each orchard. The particle size limit of 2 mm diameter was chosen based on the observation that only particles smaller than this size provide water-holding capacity to the soil, whereas particles larger than 2 mm in diameter mainly occupy space (T. Obreza, unpublished data). In each orchard, soil samples of 1,000 cm³ (61 inches³) were collected at the 10-cm and 30-cm depths, about 50 cm from the capacitance probes. Additional soil samples were collected at the 10-cm and 30-cm depths from a point located approximately between the two probe/tensiometer sets in each orchard. Thus, soil samples were collected at 10-cm and 30-cm depths from three sampling points in each orchard to determine bulk density and the fraction of bulk soil for two particle sizes, <2 mm and ≥ 2 mm diameter.

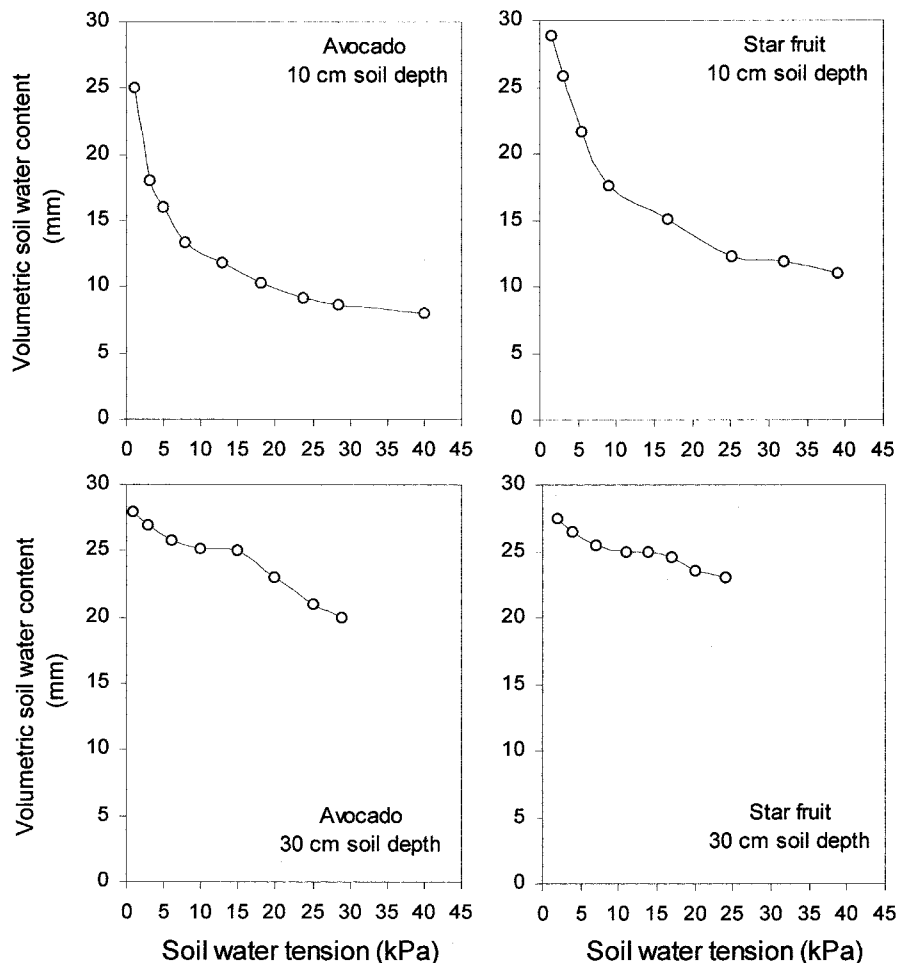


Fig. 1. In situ soil-water characteristics curves for an avocado and a star fruit orchard established in trenched calcareous soil in Homestead, Fla. Volumetric soil water content was measured with multisensor capacitance probes and soil (capillary) water tension was measured with low-tension (0 to 40 kPa) tensiometers. Measurements were made at soil depths of 10 and 30 cm (3.9 and 11.8 inches); 1 kPa = 1 centibar = 0.145 lb/inch²; 1 inch = 25.4 mm.

Results

In situ soil-water characteristic curves

The relationship between volumetric soil water content and soil water tension at the 10-cm the 30-cm soil depth in both fruit orchards is shown

Table 1. Physical properties of calcareous soil samples from two tropical fruit orchards established in mechanically excavated trenches in Homestead, Fla.

Soil depth and particle size (diam)	Avocado orchard		Star fruit orchard	
	Fraction of bulk soil (% ± SD)	Bulk density [†] (g·cm ⁻³ ± SD)	Fraction of bulk soil (% ± SD)	Bulk density (g·cm ⁻³ ± SD)
10 cm depth [‡]				
<2 mm	41 ± 3.6	0.79 ± 0.05	38 ± 3.9	0.82 ± 0.03
≥2 mm	59 ± 3.7	1.04 ± 0.06	62 ± 3.8	1.06 ± 0.08
30 cm depth				
<2 mm	29 ± 3.0	1.03 ± 0.04	27 ± 2.9	1.02 ± 0.05
≥2 mm	71 ± 2.6	1.14 ± 0.03	73 ± 2.8	1.12 ± 0.03

[‡]25.4 mm = 2.54 cm = 1.0 inch.

[†]1 g·cm⁻³ = 0.58 oz/inch³.

in Fig. 1. Averaging soil water content values common to a value of soil water tension rendered soil-water characteristic curves for both fruit orchards. Curves generated for the 10-cm soil depth had a greater inflexion than curves obtained at the 30-cm soil depth (Fig. 1). For the 10-cm soil depth in both orchards, soil water tension ranged from nearly 0 to 40 kPa, and average soil water content ranged from 7 mm (0.28 inches) in avocado or 11 mm (0.43 inches) in star fruit, to close to 30 mm (1.18 inches) in both orchards.

Volumetric soil water content at the 30-cm depth was consistently higher than at 10-cm depth, with average values remaining between 20 and 28 mm (0.78 and 1.10 inches). Maximum soil water tension values approached 30 kPa (4.35 lb/inch²) in both orchards. Soil-water characteristics curves obtained at the 30-cm depth had less pronounced inflexion points than those obtained at the 10-cm soil depth (Fig. 1).

Results from the October samplings in both orchards were similar to those obtained from March to May, with soil water content typically higher (above 20 mm) at the 30-cm depth than at the 10-cm depth (data not shown).

Soil physical properties

FRACTION OF BULK SOIL. In both orchards and at both the 10-cm and 30-cm depths, particles larger than 2 mm diameter (rock fragments) occupied a much greater fraction of the bulk soil volume than particles less than 2 mm diameter. Whereas at the 10-cm depth the ratio of percent of soil particles to rock fragments was about 39:61; at the 30-cm depth it was about 28:72 (Table 1).

SOIL BULK DENSITY. Bulk density of rock fragments ≥2 mm diameter was greater than that of soil particles <2 mm diameter in both orchards and at both soil depths. However, bulk density for both particle sizes was greater at the 30-cm than the 10-cm depth (Table 1).

Discussion

Accurate measurement of soil water status in tropical fruit orchards established in trenches in southern Florida has been difficult due to the high content of calcareous rock fragments in the soil filling the trenches. Li et al. (1998) reported the use of tensiometers placed at a 10-cm depth to aid in scheduling irrigation of tomato in calcareous plowed soil in southern Florida. Although soil water tension was not measured at a 30-cm depth in that study, it is probable that results would have been similar to those obtained at the 10-cm depth due to a more uniform soil texture in vegetable fields compared to fruit orchards. In a preliminary study conducted in a lime [*Citrus latifolia* (Tanaka), Swingle] orchard established in trenched soil, we found that low-tension tensiometers produced more consistent readings at the 10-cm than at the 30-cm depth (R. Núñez-Elisea, unpublished results). In the present study, volumetric soil water content and soil water tension data produced typical soil water characteristic curves for the 10-cm depth. However, curves of irregular appearance were obtained for the 30-cm depth, which was attributed to greater data variability due to the higher proportion of rock fragments (fragments larger than 2 mm in diameter) at the 30-cm than at the 10-cm depth in all soil-sampling sites of both orchards (Table 1). Low-tension

tensiometers may be reliable at the 10-cm depth, but at the 30-cm soil depth due to the large amount of calcareous rock fragments in the deeper soil layers within trenches. Rock fragments larger than 4 cm (1.57 inches) in diameter were frequent at the 30-cm soil depth, immediately adjacent to the tensiometer ceramic cups. Calcareous rocks are highly porous, containing many potential sites for air entrapment, which could affect the accuracy of tensiometers despite the use of slurry for better contact between tensiometer cups and surrounding soil. In contrast to tensiometers, little variation has been detected among several capacitance sensors when measuring soil water content at the 30-cm depth in trenches (Núñez-Elisea et al., 2000). The greater consistency of capacitance sensors could be due to the large volume of soil (a 10-cm tall cylinder of soil with a 10-cm ring around the edge of the PVC access tube) measured by each sensor for soil water content determination (Paltineanu and Starr, 1997).

Most tree roots and soil water depletion in tropical fruit orchards occur in the top 30-cm soil layer (Zekri et al., 1999), with a large portion of the active root system concentrated in the top 10-cm layer (Núñez-Elisea et al., 2000). Continuous measurement of soil water content with EnviroSCAN multi-sensor capacitance probes provides a clear, real-time picture of water depletion and water use by tropical fruit tree roots at different soil depths, allowing precise irrigation scheduling. However, this approach may be relatively expensive for fruit growers with small orchards. Tensiometers were more accurate at 10-cm than at 30-cm soil depth, and can be an

economical option for monitoring soil water status in trenched calcareous soil despite the lack of consistency observed at the 30-cm soil depth. Tensiometers placed at 10-cm soil depth, where most roots are concentrated, can be used to maintain soil water tension within a desired range at this depth with acceptable accuracy, since the in situ soil-water characteristic curves obtained in this study allow calculation of available soil water content for managing irrigation.

Tensiometer readings were quite variable at the 30-cm depth, but few active tree roots were found at this soil depth. After each irrigation event, tensiometer readings close to 0 kPa at the 30-cm depth would indicate that soil at this depth is at or near saturation. Thus, adjusting irrigation intervals based on tensiometer readings at 10- and 30-cm soil depths would help manage irrigation and prevent water waste and nutrient leaching outside of the active root system for tropical fruit trees in trenches.

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