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On-Farm Performance of Tensiometer and Granular Matrix Soil Moisture Sensors in Irrigated Light, Medium, and Heavy Textured Soils

Hugo Perea[1], Juan Enciso[1], John Jifon[1], Shad Nelson[2], and Carlos Fernandez[3].

[1]*Texas AgriLife Research and Extension Center, Weslaco, Texas 78596*
Current address: Arizona Department of Water Resources, Phoenix, Arizona 85012
Email: hperea@azwater.gov
[2]*Texas A&M University-Kingsville Citrus Center, Weslaco, Texas 78596*
[3]*Texas AgriLife Research and Extension Center, Corpus Christi, Texas 78406*

ABSTRACT

The main objective of this research was to evaluate tensiometer and Watermark soil water sensor performance under different field conditions. Tensiometer and granular matrix sensors were installed at 15 and 30 cm depths in three irrigated onion farms with sandy loam, sandy clay, and clay loam soil texture (light, medium, and heavy); and replicated three times. These sensors were selected because they are affordable and simple to use. Tensiometers and granular matrix sensor are delicate soil moisture devices that must be handled, installed, and maintained correctly; when properly installed they can detect plant drought stress and monitor plant water needs without wasting irrigation water supplies. Soil moisture sensor readings and volumetric water content were recorded during the entire growing season and correlated to van Genuchten water retention model. Sensor performance accuracy was poorer at 15 cm as compared to 30 cm depth, mostly attributed to more intense soil wetting and drying cycles near the soil surface. Sensors also performed poorly in the heavier textured clay soils due to high-shrinking and swelling properties in South Texas soils.

Additional Index Words: Soil water content, irrigation scheduling, available soil moisture, Granular matrix sensor, tensiometer, soil matric potential

Irrigation scheduling is defined as the decision of when and how much water to apply to an agricultural field crop. Monitoring soil moisture depletion and matching crop water requirements with irrigation are considered proper irrigation management practices to save water and energy, increase yield, and reduce environmental problems. Correct irrigation scheduling minimizes crop water stress and maximizes yield, minimizes fertilizer loss via runoff and deep percolation, and controls salinity problems.

Various irrigation control devices are available to match plant water demand. These devices include sensors to measure soil wetness and weather sensors for crop reference evapotranspiration (Hillel, 1998). The amount of soil water can be measured by direct soil sampling and non-destructive methods.

Direct soil sampling is expensive and time consuming, and it is generally taken as a reference method to calibrate other soil moisture devices. Non-destructive methods include measuring matric potential and gravitational water potential, electrical conductivity of porous space (Spaans and Baker, 1991; Yoder et al., 1998; Scanlon and Andraski, 2002; Huang et al., 2004; Chow et al., 2009), travel time of electromagnetic techniques (Robinson et al., 2003; Jones et al., 2005; Blonquist et al., 2005; Evett, 2007; Robinson et al., 2008), heat conductivity of soil (Robinson et al., 2008; Steele-Dunne et al., 2010), or counts of neutrons in soil water (Carneiro and Jong, 1985; Evett, 2008).

Tensiometers and granular matrix sensors measure suction and conductance of soil. Warrick (2003) indicated that soil water is in equilibrium with the water inside of a porous ceramic cup of a tensiometer in which the pressure deficit is measure with a vacuum gauge. Muños-Carpena et al. (2005) and Thompson et al. (2006) mentioned that tensiometer device is widely used for irrigation scheduling in commercial farming and research studies, but this device requires regular maintenance to work properly. Their restricted pressure tension range of operation can be a limitation for its use. A correct estimation of the soil water potential in the tensiometer is highly dependent upon soil type, soil temperature, and soil salinity (Hanson et al., 2000; Muñoz-Carpena et al., 2005).

The electrical conductivity of a porous media in a granular matrix sensor is measured using electrical resistance blocks with two electrodes imbedded in a porous material, such gypsum or sand-ceramic mixture. Moisture moves in and out when soil dries. The electrodes measure the resistance to electric current when electrical energy is applied. The more moisture is in the block, the lower the resistance reading, indicating more available moisture. The electrical resistance blocks use gypsum or similar material to buffer against salts that would affect the resistance reading. The sensor using a granular matrix sensor seems to work well and lasts for longer time as compared to gypsum blocks. Granular matrix sensors are attractive for irrigation scheduling use on commercial farms because its low price (Hanson et al., 2000). Scalon and Andraski (2002) implies that this sensor is inexpensive, simple to use and install, along with simple preparation and minimal maintenance requirements. Although the manufacturer claims that granular matrix sensor works up to 200 kPa tension, researchers have only calibrated this sensor in the pressure range of 10 kPa to 100 kPa (Thompson and Armstrong, 1987; Shock et al., 1998). Périès and Enciso (2009) reported from a laboratory study that granular matrix sensors did not provide good readings on higher clay content soils after a certain water depletion point was reached, mainly attributed to cracking of the soil, and loss of soil-to-sensor contact leading to a high variability of readings. The granular matrix sensor can overestimate soil water content on loamy sand (Huang et al., 2004), sandy loam (Thompson et al., 2006), or loamy soils (Proulx, 2001), especially under rapidly drying conditions, due to a slow sensor response. Some studies have even found that granular matrix sensors have responded more slowly than tensiometers (Meron et al., 1996; Hanson et al., 2000; Taber et al., 2002).

Several studies have also found good correlation coefficients between soil water potential and granular matrix sensor and tensiometer readings (Hanson et al., 2000; Thompson et al., 2006). Thompson et al. (2006) reported strong correlations (r^2) ranging from 0.96-0.98 for tensiometers and from 0.91-0.95 for granular matrix sensors; more studies are needed to compare these sensors under different soil types.

In this paper, two soil moisture devices, tensiometer and granular matrix sensor, were evaluated for their response and appropriateness for irrigation scheduling on onion farms. They were installed in three soil types at two different depths and related against the van Genuchten retention curve model which is based on soil texture and bulk density as one of the input options. Criteria used to evaluate these instruments were: ease of operation, ease of installation, maintenance and cost. Moreover, advantages and limits of the proposed sensors working under field conditions were discussed.

MATERIALS AND METHODS

Three commercial field sites were selected based on soil characteristic differences to compare two soil moisture devices under light, medium, and heavy soil textures where field sites were planted with different varieties of onions. The commercial field sites were located in the Lower Rio Grande Valley (LRGV) of South Texas.

Description of the Sites

Site A consisted of a Sandy Loam texture (clay 17%, silt 15%, sand 68%) to a soil depth of 30 cm. Sweet onion variety, Legend 10-15, was planted four onion rows per bed with seeds spaced 18 cm apart on 13 Oct 2008. Netafim drip line was buried at 14 cm closer to the root zone and sand media filtration system was used to irrigate this field during entire season. Onions were harvested on 03 Apr 2009 with a yield production of 284,050 bulbs per hectare.

The second site, Site B, consisted of a Sandy Clay texture (Clay 35 %, Silt 15%, Sand 50%). Sweet Sunrise onion variety was planted on 22 Oct 2008 with 2 rows per bed and seed spaced 18 cm apart. T-Tape irrigation system was installed in the center of the 15 meter-long bed and buried to a depth of 15 cm. Onions were harvested on 30 Apr 2009 with a yield production of 109,745 bulbs per hectare.

The last site, Site C, was flood irrigated using furrow irrigation. This site had a heavy texture classified as a Clay Loam soil (Clay 35%, Silt35%, Sand 30) to a 30 cm depth. Site C was planted with Sweet Sunrise onion variety on 13 Oct 2008 with 4 rows per bed and 18 cm seeds spacing. Onions were harvested on 23 Apr 2009 with a yield of 242,369 bulbs per hectare.

Soil moisture sensor installation

Granular matrix sensors were installed at two depths (15 cm and 30 cm) and replicated three times 15 cm apart from each other. Proper preparation and installation of the granular matrix sensor is vital to its operation. Sensors were soaked overnight and installed wet. An access hole to the desired depth using a PVC pipe with 1.27 or 1.90 cm interior diameter was made to install sensor. The hole was filled with water, then sensor was firmly and snugly seated in the bottom of the access hole using the PVC pipe. Finally, the hole was back filled with soil and tamped firmly.

Tensiometer required that the porcelain cup had good hydraulic contact with the surrounding soil so that water could freely move into and away from the cup as efficiently as possible. The tensiometer was filled with clean deionized water allowing it to stand in a vertical position for at least 30 minutes so that the ceramic tip was totally saturated. A small hand vacuum pump was used to remove air bubbles and helped to test for air leaks. This service was necessary before installation as well as periodically in the field. In this experiment, tensiometers were installed at two depths (15 and 30 cm) and replicated 3 times in each onion field.

Determination of soil physical properties

Soil texture was determined by using the hydrometer method which determines soil particle size distribution. The soil texture is the composition of the soil particles expressed as the percentage of clay, silt, and sand. Bulk density was determined using the Madera probe developed by the USDA for neutron probe calibration and varies from soil texture (Evett, 2007).

Estimation of soil hydraulic parameter

Water characteristic parameters for the van Genuchten model (1980) were determined from the percentage of sand, silt, clay, and bulk density using the Rosetta software (Schaap et al., 1998). This software employs artificial neural network approach and provides accurate prediction of the unsaturated hydraulic conductivity parameters which are shown in Table 1.

After these parameters were determined, tensiometer and granular matrix sensor readings were compared to van Genuchten model by computing the Root Mean Squared Error (RMSE). The RMSE is a measure of accuracy between sensor and water retention curve values.

RESULTS AND DISCUSSION

Granular matrix sensor and tensiometer soil moisture sensor data are graphed and compared to the water characteristic curve proposed by van Genuchten (1980) in which the effective saturation (Se) varies from zero to one as abscissa and water potential as ordinate. These relationships are presented separately for each site for the following sections. Available water content was in the range from 0.28 to 0.36 for the soils tested in onion fields.

Site A

The water characteristic curve proposed by van Genuchten and data obtained from two soil moisture sensors that were tested in an onion field are plotted in Fig. 1. The upper soil layer (0-15 cm) presented water content data closer to the residual water content so that effective saturation is in the range from 0 to 0.4. Both, granular matrix sensor and tensiometer, soil moisture sensors tested underestimated soil matric potential during the entire season, when compared to the model curve fit (Fig.1). The deeper soil moisture sensors (Fig. 1b) showed smaller soil water content variations during the entire season indicating that irrigation supplied enough water to keep this layer in field capacity. Granular matrix sensors performed better under field capacity conditions (Fig. 1b). When soil dries, effective saturation values are more disperse. Tensiometer readings were more accurate than granular matrix sensor readings at 30 cm depth, when the sensor readings were compared to the water retention curve (Table 2).

In spite of scattered water content variation for

Table 1. Soil hydraulic parameters for the van Genuchten characteristic curve.

Site	Depth (cm)	θr (cm^3/cm^3)	θs (cm^3/cm^3)	α (1/cm)	n	Ks (cm/d)	rb (gr/cm^3)
A	15	0.06	0.42	0.0247	1.45	42.51	1.44
	30	0.05	0.33	0.0373	1.27	10.66	1.76
B	15	0.07	0.42	0.0203	1.33	15.38	1.49
	30	0.07	0.39	0.0231	1.24	7.91	1.60
C	15	0.09	0.50	0.0122	1.44	31.57	1.19
	30	0.08	0.44	0.0112	1.45	9.71	1.40

Note: qr is residual water content; qs is saturated water content; a is related to the inverse of the air entry suction; n is a measure of porous-size distribution; Ks is saturated hydraulic conductivity; and rb is bulk density .

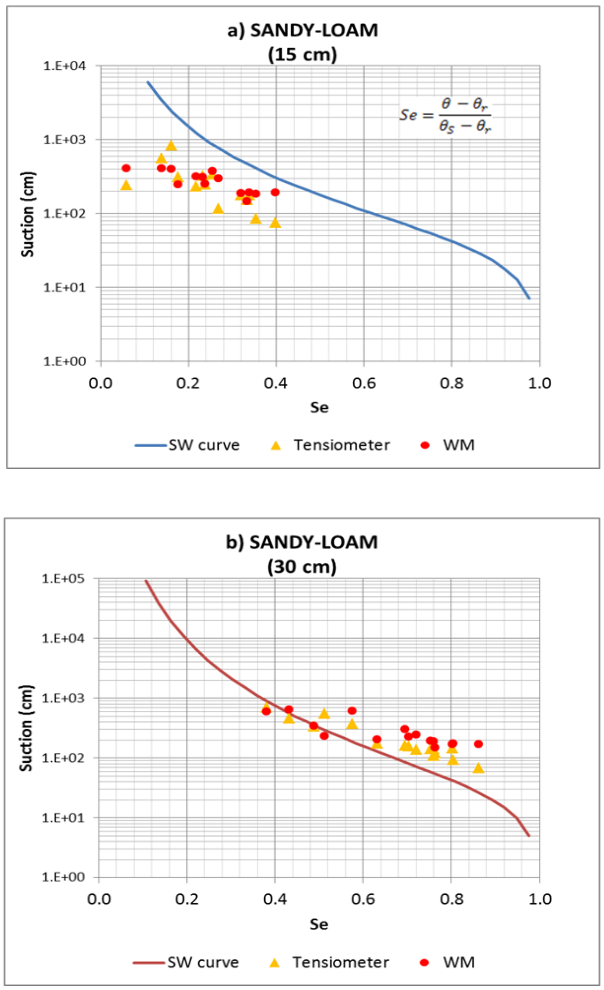

Fig. 1. Granular matrix sensor and tensiometer readings for the site A at two depths: a) 15 cm and b) 30 cm.

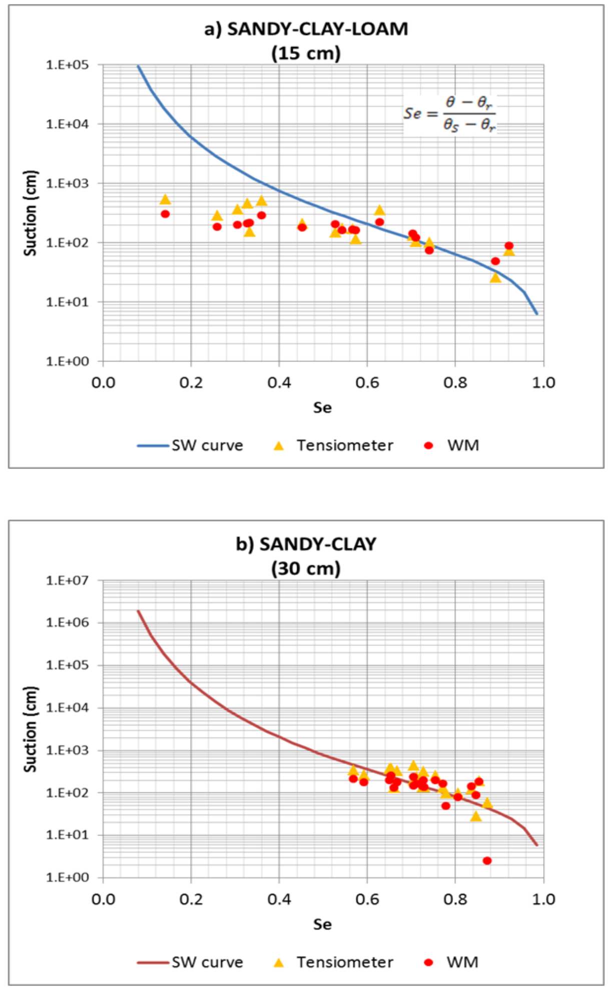

Fig. 2. Granular matrix sensor and tensiometer readings for the site B at two depths: a) 15 cm and b) 30 cm.

both soil moisture sensors, available water content was low indicating that some stress periods may have occurred during the onion season.

Site B

Granular matrix sensor readings behaved similar to the tensiometer readings at both depths in site B (Fig. 2). Good range of sensor's reading response to change in moisture was observed for the upper soil layer (0-15 cm), the range varied from field capacity to residual water content. It was noticed that the upper layer was wetted during irrigation and dried faster because of its interaction with atmospheric conditions. Shallow sensors are not good indicators of a good irrigation management and it might have poor response.

The 30 cm soil depth moisture sensors presented 0.5 to 0.8 degree of saturation indicating that a small

Table 2. RMSE between moisture sensors and the van Genuchten model.

Site	Depth (cm)	Suction RSME (cm)	
		Tensiometer	Granular matrix sensor
A	15	6927	6894
	30	174	219
B	15	844	907
	30	142	72
C	15	1416	1335
	30	113	133

variation in available water content has occurred during the irrigation season. Readings for both sensors yielded almost the same trend than the van Genuchten water retention curve model. All the sensors performed better at deeper installation for both sensors (Table 2).

Site C

Site C presents heavier soil texture than the other sites. The soil moisture readings were more scattered for both sensors and depths. Most of the readings taken during the entire onion season underestimated suction from the curve model fit, according to the water retention curve of this soil texture (Fig. 3). Effective saturation closer to a value of 0.16 might indicate that sensor's readings were taken just after the onion was irrigated (Fig. 3a). Readings from deeper sensors were mainly concentrated in the range 0.4 to 0.8 of the effective saturation and the tensiometers readings were closer to the van Genuchten water retention curve model.

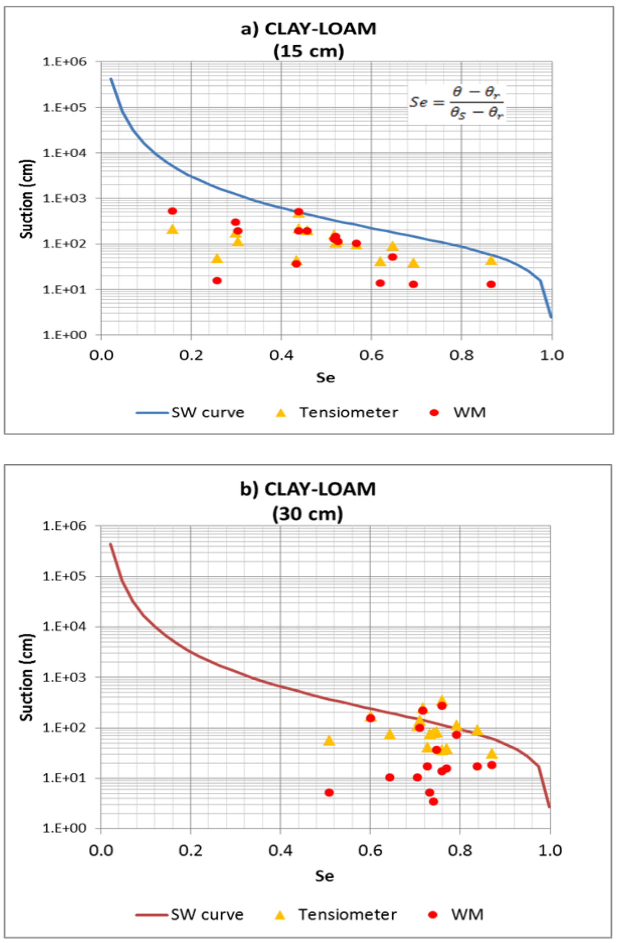

Fig. 3. Granular matrix and tensiometer readings for the site C at two depths: a) 15 cm and b) 30 cm.

In the three sites, granular matrix sensor readings behaved similarly to tensiometer readings. However, granular matrix sensor performed better to changes in soil moisture content at 30 cm depth for the sandy loam and sandy-clay-loam soils. As with tensiometers, poor hydraulic contact apparently occurred between soil and sensor cup for the Site C with Clay Loam texture.

Both sensors performed better in Sandy Clay soil texture (Table 2); however, suction was slightly underestimated when compared to the model for both sensors during the whole season in this soil texture.

Tensiometers generally responded well to changes in soil moisture, although poor response occurred for the 15 cm depth at the three sites. Possible causes of poor responses include poor hydraulic contact between the porous cup and three soil texture due to shrinkage; leaks caused by a poor seal or a cracked porous cup; and excessive drying.

Although tensiometers were periodically maintained, lack of irrigation immediately following maintenance could have dried the porous cup and prevented a response to subsequent irrigations.

SUMMARY AND CONCLUSIONS

Performance of two moisture sensors devices were assessed in three onion fields by correlating Tensiometers and granular matrix sensor readings and the soil water characteristic curve proposed by van Genuchten (1980). Sensors were installed in three different soil textures, sandy loam, sandy clay, and clay loam at 15 and 30 cm depths.

Both sensors performed poorly at 15 cm depth probably because of management and maintenance problem. However, sensors installed in Sandy Clay soil texture (site B) performed better than the others two sites. Although, deeper sensors performed better during the whole season, water contents were still slightly underestimated for both sensors. Sensors installed close to the soil surface might be affected by wetting and drying soil phases, poor maintenance, and installation.

Overall, tensiometers and Granular matrix sensor are delicate soil moisture devices that must be handled, installed, and maintained correctly; when properly they used can detect plant drought stress and monitor plant water needs without wasting irrigation water supplies. We recommend installing these sensors at depth deeper than 30 cm to avoid problems of losing contact with the sensor because of the drying of the soil.

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