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Laboratory Accuracy of Soil Moisture Sensor Irrigation Controllers

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It has been demonstrated that soil moisture sensor systems (SMSs) can reduce irrigation application in Florida. However, SMSs have not been tested under Florida soils irrigated with reclaimed water, which contains salts that can affect the measured soil water content. The objective of this research was to test different commercially available SMSs under controlled conditions, and analyze their responses and readings under different levels of water salinity and temperature. Three brands/models were selected for this experiment: Acclima/SCX, Baseline/WaterTec S100, and Dynamax/IL200-MC. Different design methods were pretested. The selected method consisted of containers manufactured so that they could be saturated from the bottom to minimize entrapped air and fitted with sintered metal filters to allow vacuum application for water removal in a timely manner. The containers were installed in a controlled-temperature chamber so that they could be saturated and dried down across three temperatures (5, 25, and 35 °C). The water applied will have an electrical conductivity of 0.0, 0.7, and 5.0 dS·m^{-1}. Each container was placed on a platform-scale to determine soil-water loses, by weight variation over time. The scale readings are compared to the SMS readings, and a calibration curve is developed through regression analysis. Preliminary outcomes show that most treatments resulted in linear regressions with R^2 values higher than 0.92, corroborating that this laboratory design is adequate for verifying the precision and accuracy of the SMSs tested over a range of salinity values, water contents, and temperatures.

New commercially available soil moisture sensor systems (SMSs) have been designed to allow or bypass the scheduled irrigation cycles of automatic irrigation systems depending on the soil water content at the programmed start time. The SMSs consist of a probe and a controller. The probe is inserted in the root zone and the controller is connected to the irrigation timer. In the controller, the user can set a soil water content threshold.

These SMSs respond to the electromagnetic properties of the soil, more specifically to the dielectric permittivity. Of all the constituents of the soil, water is the only one with a high dielectric permittivity. Therefore, changes in the water volume have the most significant effect on the total permittivity of the soil. The SMSs operate by sending a signal to the soil environment. This signal is distorted by the amount of dielectric permittivity, which is then translated to a specific soil water content. If the soil water content is above the threshold set in the controller (too wet) the SMS will bypass that scheduled irrigation cycle, and vice versa.

Data have demonstrated that SMSs can save irrigation water in Florida (Cardenas-Lailhacar et al., 2008; Haley et al., 2007; Shedd et al., 2007). However, SMSs have not been tested under Florida soils irrigated with reclaimed water. This source of irrigation contains salts that can affect the dielectric permittivity and hence, the readings of SMSs when measuring the soil water content (Robinson et al., 2003). Likewise, temperature affects the electric properties of the soil, which can alter the accuracy of the SMS readings (Evett et al., 2006).

The objective of this research is to test different commercially available SMSs under controlled conditions, and analyze their responses and readings under different levels of water salinity and temperature. This paper describes some pretesting aspects of the experimental design, as well as preliminary results.

Materials and Methods

This study is being conducted in a controlled-temperature chamber at the University of Florida in Gainesville. Inside the chamber, platform scales with a resolution of 0.02 kg were set [Champ SQ base with CW-11 Indicator (Ohaus Corp., NJ)]. Three SMS brands/controllers/probes were selected for this experiment: Acclima/SCX/Digital TDT (Acclima Inc., Meridian, ID), Baseline/WaterTec S100/biSensor (Baseline Inc., Meridian, ID), and Dynamax/IL200-MC/SM200 (Dynamax Inc., Houston, TX). The controllers of these systems can display the volumetric water content of the sampled soil.

Plastic containers with overall dimensions of 55 × 38 × 25 cm high were packed with 28 L of soil extracted from the top 15 cm of an Arredondo fine sand (loamy, siliceous, semiactive, hyperthermic Grossarenic Paleudult) (Thomas et al., 1985; U.S. Dept. of Agriculture, 2007). The containers were built such that they could be saturated with water from the bottom (to minimize entrapped air that could affect the SMS readings) and, afterwards, to allow the free drainage of excess water. Each container was placed over a platform scale to determine soil water lose, by weight variation over time. The scale readings were corrected through the gravimetric method (Gardner, 1986) from soil samples at the end of each test. The scale readings were transformed to volumetric water content, and then compared with the SMS readings. Calibration curves were developed through regression analysis.

Experimental design pretest. Different experiment design

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methods were pretested to analyze their feasibility and convenience. One SMS probe was installed in each of three containers. The temperature of the chamber was set at 25 °C. The water applied to test this experimental stage was tap-water. In order to decrease the amount of time that it would take to complete one testing batch, a controlled vacuum force applied to the containers was considered, which would extract part of the water retained by the soil. Three different design methods were tested:

• The bottom of the container had two through-wall PVC 3/4-inch fittings, coupled with plastic tubes, which could be connected to a vacuum pump. A woven wire cloth with square openings of 1 mm was placed on top of the openings. The bottom of the container was filled with gravel and the same size woven wire cloth was placed over the gravel to avoid soil movement below this point. The soil was hand-packed on top of the wire cloth.

• Suction was provided from the bottom of the container having four through-wall PVC 1/2-inch fittings with plastic tubes connected to a vacuum pump. A plastic mesh 1.5 cm high with square openings of 15 cm was placed on the bottom of the container, a woven wire cloth with square openings of 1 mm was placed on top of the plastic mesh, and then the soil was hand-packed on top of the wire cloth.

• The bottom of the container had four through-wall PVC 1/2-inch fittings, coupled with plastic tubes, which were used for gravitational drainage. A woven wire cloth with square openings of 1 mm was placed on top of the through-wall fittings. The container was fitted with two sintered metal filters (porous tubes 10-micron filter grade) located inside the container at 3.5 cm from the bottom. The soil was hand-packed, making sure that the sintered metal filters had good contact with the surrounding soil.

Of the three system designs tested, none of them showed a better performance for filling the soil with water from the bottom. For vacuum purposes, however, only the one with the sintered metal filters worked properly throughout the experiment. The other two systems worked when the soil was close to saturation; but when the soil decreased its water content, even when applying suction for more than 1 h, the soil water content did not decrease significantly. Hence, the actual tests will be carried out in containers with a combination of the sintered metal filters apparatus and the two through-wall PVC 3/4-inch fittings.

EC and temperature testing. The containers will be saturated and dried down across three temperatures: 5, 25, and 35 °C. The water applied will have three levels of salinity: 0.0, 0.7, and 5.0 dS·m^{-1}. Each SMS brand/controller/probe will be replicated three times. After developing the regression analysis for each of them, a contrast analysis will be performed between the treatments within a brand, to evaluate if there are statistical differences. These analyses will be performed using the statistical analysis software (Statistical Analysis System, 2008).

Results and Discussion

Results presented here suffice to show the performance of the lab setup, but do not include all the possible combination treatments between temperature and salinity that will be conducted in the future.

Pretest. During the pretest stage (to analyze the best experimental design) the relationship between the scale and sensor readings was calculated through linear regression analysis. High R^2 values for Dynamax, Baseline, and Acclima systems were obtained: 0.977, 0.985, and 0.996, respectively. These results gave a high confidence of the readings of the actual soil water content, and verified that any of the laboratory designs tested was adequate to analyze the accuracy of the SMSs.

EC and temperature testing. By the date of this manuscript, three treatments were completed after the pretest stage, which included the combinations of 0.0 dS·m^{-1} at 25 °C, 0.0 dS·m^{-1} at 35 °C, and 0.7 dS·m^{-1} at 35 °C. Table 1 summarizes the results of the regression analyses for these treatments. Linear R^2 values greater than 0.92 were obtained in every treatment, except for Dynamax at 0.0 dS·m^{-1} and 35 °C that resulted in R^2 = 0.81. These values indicate that the different brands showed a high precision to estimate the soil water content at the salinities and temperatures tested. Moreover, linear R^2 greater than 0.93 were verified for every single replication (data not shown), which indicate a high precision of all of the individual units tested. However, none of the slopes and intercepts matched exactly the 1:1 line, so calibration of these systems is necessary if accurate readings are required.

Table 2 shows the contrast analyses that were performed between treatments within a brand. Results show that increasing the temperature from 25 to 35 °C and/or the salinity from 0.0 to 0.7 dS·m^{-1} did not affect the accuracy nor the precision of Acclima and Baseline systems. In the case of Dynamax tested at 35 °C, however, increasing the salinity from 0.0 to 0.7 dS·m^{-1} had a significant effect on the slope of the regression. These preliminary results suggest that Dynamax systems are more sensitive to changes in the salinity of the soil environment, and site specific calibrations should be performed to achieve an adequate control of irrigation.

Finally, these results corroborate that the laboratory design is adequate for verifying the precision and accuracy of the SMSs

Table 1. Regression analysis by treatment.

	Treatment		Regression analysis		
Brand	dS·m^{-1}	°C	R^2	Slope	Intercept
Acclima	0.0	25	0.980	0.863	4.02
	0.0	35	0.981	0.982	2.41
	0.7	35	0.986	0.940	3.66
Baseline	0.0	25	0.982	0.910	–2.68
	0.0	35	0.977	1.004	–2.40
	0.7	35	0.931	0.930	0.12
Dynamax	0.0	25	N/A	N/A	N/A
	0.0	35	0.811	1.210	2.76
	0.7	35	0.921	1.083	5.00

N/A = not applicable.

Table 2. Contrast analysis between treatments within a brand.

		Treatment contrasts					
Brand	Analysis	dS·m^{-1}	°C		dS·m^{-1}	°C	*P*-value
Acclima	Regression	0.0	25	vs.	0.0	35	0.1765
	Regression	0.0	35	vs.	0.7	35	0.1990
	Regression	0.0	25	vs.	0.7	35	0.5292
Baseline	Regression	0.0	25	vs.	0.0	35	0.8794
	Regression	0.0	35	vs.	0.7	35	0.3253
	Regression	0.0	25	vs.	0.7	35	0.2557
Dynamax	Regression						0.0004
	Intercept	0.0	35	vs.	0.7	35	0.1195
	Slope						<0.0001

tested over a range of salinity values, water contents, and temperatures.

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