SENSOR-BASED IRRIGATION SCHEDULING IN COTTON PRODUCTION

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Abstract. The overall objective of this study was to determine the feasibility of utilizing sensor-based soil water monitoring techniques in southeastern Coastal Plain soils to more effectively manage agricultural water resources. Tests were conducted to determine the effects of installation methods (Slurry and Direct) on accuracy of two Multi-sensor capacitance moisture probes (EnviroSCAN and AquaSpy) for soil moisture monitoring. A further aim of the trial was to determine the water use efficiency of four cotton cultivars under multiple irrigation regimes. The results showed that, if installed and calibrated properly, the capacitance moisture probes can accurately measure volumetric soil water contents for real-time site-specific irrigation scheduling. The "Slurry" installation method over estimated volumetric soil water contents in the sandy Coastal Plains' soils at the experiment site. There were significant differences in water use efficiency among the cotton varieties. Highest water use efficiency values were 0.55 kg seed cotton/m^3 water applied in 2008 and 0.788 kg/m^3 in 2009.

INTRODUCTION

Competition for limited water resources is one of the most critical issues being faced by irrigated agriculture in the United States. The recent drought periods and legal conflicts between states have prompted an interest in improved irrigation scheduling methods and enhanced water use efficiency of cotton cultivars in the southeast.

Several irrigation scheduling methods (soil moisture monitoring, pan evaporation, and climate based) tested at Clemson have shown that sensor-based irrigation significantly increased cotton yields and provided a monetary savings compared to other methods (Khalilian et al, 2008). Real-time, accurate, and continuous soil moisture measurements at specific depths are essential for successful irrigation scheduling. Multi-sensor capacitance probes have been used to accurately measure volumetric soil water contents in a soil water monitoring system (Paltineanu and Starr, 1997). However, Evett and Steiner (1995) reported that the capacitance probe was unacceptable for water content measurements with fine sandy loam soils. Soils in the Coastal Plains region usually have a structure that exhibits three distinct layers: A horizon (sandy to loamy sand), E horizon or hardpan layer (yellowish brown sandy to sandy clay), and Bt horizon (sandy clay loam). Currently there is no published data on the performance of capacitance probes in multi-layer soils of the Coastal Plains region.

Increasing water use efficiency (WUE) and drought tolerance in cotton is highly valuable to U.S. and world agriculture. Screening cotton varieties for water use efficiency would help growers to maintain or increase crop production with less water.

The objectives of this study were to: a) determine the effects of installation methods (Slurry versus Direct) on accuracy of capacitance moisture probes for soil moisture monitoring in Coastal Plains' soils; and b) quantify the water use efficiency of different cotton cultivars.

MATERIALS AND METHODS

Multi-sensor capacitance probes (AquaSpy™ and Sentek EnviroSCAN®) were used to compare two probe installation techniques in a coastal plain soil. For the "Direct" installation method, a PVC access tube was installed by inserting it through the guide block (Figure

Figure 1. Probe installation techniques: Direct (left) and Slurry (right)

1, left) into the soil using a dry drilling technique explained in Paltineanu and Starr (1997). For the "Slurry" installation method, a hole (6 mm larger than the probe's outside diameter) was drilled using a specially designed auger. The slurry (made from the excavated sandy clay loam soil) was poured into the hole (Figure 1, right), filling the space between the probe and the hole wall.

The accuracy of each sensor in measuring the volumetric soil moisture content was determined using standard gravimetric techniques. A 1.2m trench was first dug approximately 40 to 50cm from the sensors to ease access for soil sample collection from each 10cm soil layer depth. Two or three undisturbed soil cores, centered at each of the 10-cm spaced sensors depths, were collected in brass rings from about 12mm from the wall of the probe access pipe. The Sentek and AquaSpy probes contain sensors at depths of 10, 20, 30 40, 50, and 60cm. Each sensor consists of two conductive rings (brass) forming the "capacitor" connected to circuitry. The AquaSpy™ probes contain a flexible circuit board within sealed construction that performs the same function and contains sensors at similar depths. The volumetric moisture contents (VMC) were regressed against the sensor reading to determine the relationships between the two variables.

Tests were conducted in a 2-ha section of a field at the Edisto Research and Education Center, near Blackville, SC. The test field was equipped with a 76-m long linear-move irrigation system (LMIS) modified to apply variable-rate irrigation (VRI) with low energy precision application (LEPA) drops.

A commercially available Veris 3100 soil electrical conductivity (EC) measurement system (Lund et al., 1999) was used to map variations in soil texture across the field. The test field was then divided into three management zones based on the EC data. The following treatments were replicated three times using a Randomized Complete Block design with treatments arranged in a factorial design:

- Four cotton varieties: Delta and Pine Land 0924, 0920, 0935 and 0949, and
- Four irrigation rates: 0, 30, 60, and 90% of full crop water requirements. This requirement was

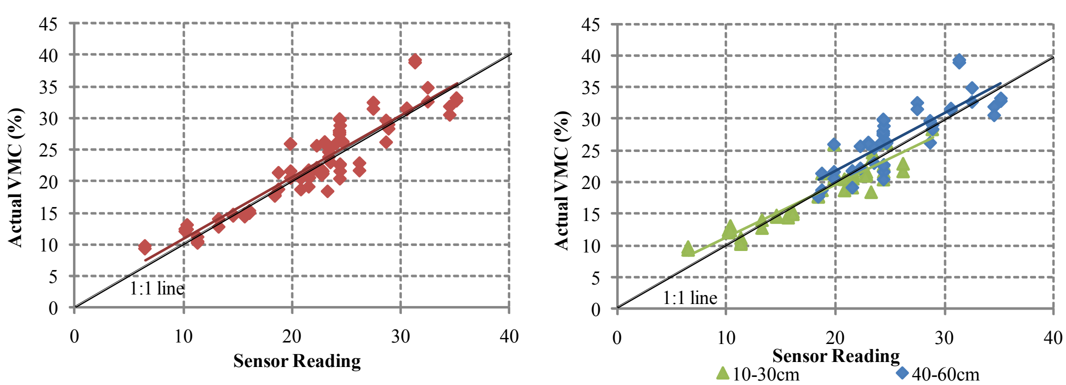

Figure 2. VMC vs. the Sentek sensor readings for all data (left) and two different horizons (right).

based on the percentage of total water needed to bring the soil water to field capacity.

The required irrigation rates were calculated based on the AquaSpy capacitance probes data. Irrigation depth was calculated by adding the depleted water in each soil layers. The 100% irrigation treatments were calculated using the sensor data from the corresponding 90% treatment plot. The 100% depths were then averaged for each zone and then applied to the plots according to the irrigation treatment.

Cotton was harvested on November 9, 2009, using a spindle picker equipped with an AgLeader® yield monitor. The WUE was calculated by dividing yield in each plot by the amount of water applied to the plot (water beneficially used).

RESULTS AND DISCUSSION

Probe Calibration:

No gaps were found between the soil and access tubes for the probes installed using the direct drilling method. Plots of VMC versus the Sentek probe readings using all of the calibration data (left) and individually the topsoil (A plus E horizons: 10-30cm) layer and the subsoil (40-60cm) layer (right) are shown in Figure 2.

There was a strong positive linear correlation between sensor readings (SR) and the actual VMC (R^2=0.8562, standard error=2.73%) for all data. As given in Eq. 1, the slope of the regression line was near unity and the bias was small (about 1.1%).

$$VMC = 0.9861 * SR - 1.0611 \quad (1)$$

The correlations were not improved when topsoil and subsoil data were regressed separately. The regression analysis suggests that the calibration using the Sentek probes can be represented as a single equation (1) for the entire profile with minimal errors.

Figure 3 shows calibration curves for AquaSpy™ sensor readings using all data (left) and individually the topsoil (10-30cm) layer and the subsoil (40-60cm) layers (right). There was also a positive linear correlation between AquaSpy™ sensor readings and the actual VMC with an R^2 value of =0.680, standard error of 4.24%, and defined by:

$$VMC = 0.6033 * SR - 21.372 \quad (2)$$

The correlations were significantly improved when topsoil and subsoil data were regressed separately. These relationships are given in equations 3 and 4 for topsoil sand and subsoil clay, respectively:

$$VMC_s = 0.3205 * SR_s - 6.4753 \quad (3)$$

$$VMC_c = 0.4623 * SR_c - 7.5982 \quad (4)$$

The R^2 values for depths 0-30cm and 40-60cm were 0.729 and 0.759, respectively. Results suggest that for the AquaSpy™ probes, separate equations should be used for each soil layer under Coastal Plain conditions.

Water Use Efficiency:

At the beginning of the test, all plots were irrigated five times (57 mm total) to get crop established and maintain early uniform growth. The total rainfall during growing season (June 2 to September 15) was 296 mm.

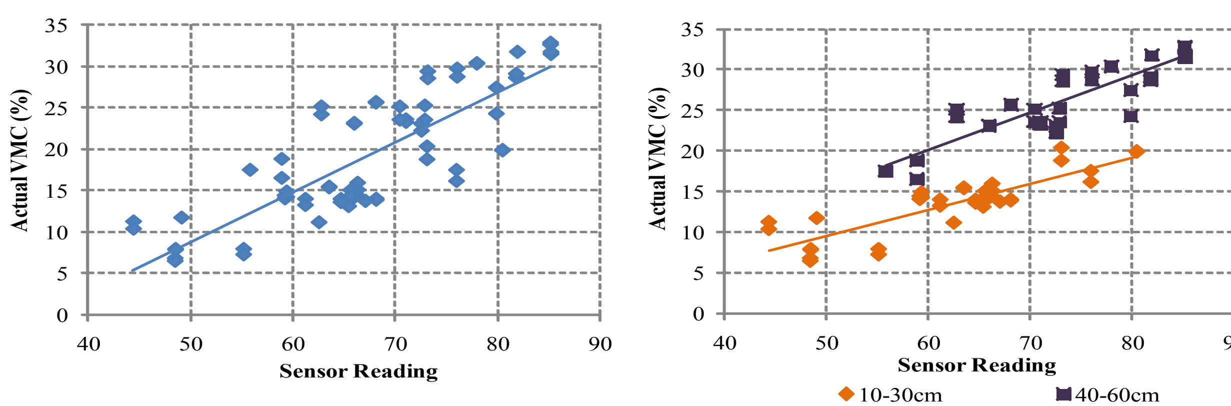

Figure 3. VMC vs. the AquaSpy sensor readings for all data (left) and horizon separation (right).

A total difference of 254 mm in irrigation water was achieved between the maximum and minimum application in the plots of DP 0924. There was no difference in the amount of water applied for each zone and cultivar for each irrigation regime. During VRI events, runoff was minimized as much as possible by applying irrigation treatments in four separate events.

Figure 4 shows the effect of irrigation treatments on seed cotton yields. Different varieties showed different responses to the amount of water applied during the 2009 growing season. Within a given cotton variety, there were no statistical differences in seed cotton yields between 60 and 90% irrigation treatments. Maximum yield for all cotton cultivars was obtained around 520 mm total water applied (60%). Except for DP 0935, yields decreased when more water was applied. DP 0920 and DP 0924 cultivars yielded significantly higher than DP 0949 and DP 0935 for dry land cotton. For the optimum irrigation rate (60%), only DP 0949 yielded significantly less than the other three cultivars.

Similar results were obtained for water use efficiency (WUE) for these cultivars. The WUE values were calculated for each plot by dividing the cotton yield (kg/ha) by the amount of water applied (precipitation plus irrigation) and by the ET_c. WUE values based on water applied were 0.77, 0.76, 0.74 and 0.68 kg seed cotton /m^3 for DP 0920, 0924, 0935 and 0949, respectively. Under the 2009 growing conditions, DP 0949 had significantly lower WUE than the other three cotton cultivars. The ET_c-based WUE values for the same cultivars were 0.71, 0.71, 0.69, and 0.64 kg seed cotton /m^3, respectively.

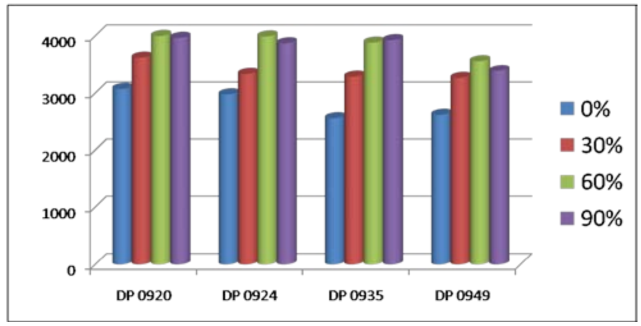

Figure 4. Effects of irrigation treatments on seed cotton yields.

CONCLUSION

It was found that positive linear calibrations can be used to describe the relationship between the soil volumetric moisture content and sensor readings for both the AquaSpy™ and the Sentek EnviroSCAN® probes and that both probes can be used to accurately measure volumetric soil moisture contents, if installed and calibrated properly. The correlation of actual and measured volumetric moisture content for the AquaSpy™ probes suggested that separate equations should be used for each soil layer under coastal plain conditions with texturally-different soil layers. However, with the Sentek probes, a single calibration equation can be used for the entire profile. It was determined that a direct installation of the probes should be used rather than a slurry mix method. The slurry method was found to overestimate the volumetric moisture content in sandy soils and encourage root growth along the length of the slurry.

Different varieties showed different responses to the amount of water applied. Within a give cotton variety, there was no significant difference in seed cotton yields between the 60 and 90% irrigation treatments. This implies a 30% water savings and thus warrants further detail investigation under different field conditions and seasons.

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