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SENSORS FOR EFFECTIVE IRRIGATION SCHEDULING AND IMPROVED WATER USE EFFICIENCY OF COTTON CULTIVARS

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ABSTRACT Competition for water with the environment has and will continue to demand more water or severely limit other uses. Many existing sources of water are being stressed by increasing irrigation needs that currently account for about 65% of the national water withdrawals. The overall objective of this study was to determine the feasibility and improve the utility of sensor-based soil water monitoring techniques in south-eastern Coastal Plain soils to more effectively manage irrigation and conserve water resources. Field experiments were conducted to determine the accuracy of two multi-sensor capacitance moisture probes (EnviroSCAN and AquaSpy) using two installation techniques (Slurry and Direct). The results showed that, if installed and calibrated properly, these 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 a sandy Coastal Plain soil. Multi-sensor probes were also used to determine the water use efficiency of four cotton cultivars under multiple irrigation regimes. There were strong correlations between the depths of seasonal irrigation and seed cotton yields. Maximum yield for all cotton cultivars was obtained around 520 mm total water applied (irrigation plus rain). Yields decreased when more water was applied. There were significant differences in water use efficiency among the cotton varieties, with the highest values of 0.77 kg of lint cotton per m3 of total applied water and 0.71 kg/m3 of crop evapotranspiration (ETc). Results are beneficial to growers to help select more efficient varieties to maintain or increase crop production with less water.

Keywords: Irrigation scheduling, Capacitance probes, Water use efficiency.

INTRODUCTION Competition for limited water resources is one of the most critical issues being faced by irrigated agriculture in the United States. Even in the humid southeastren U.S., recent drought periods (1998-2002, & 2007) and trans-boundary water conflicts between neighbouring states have elevated the importance of water resources conservation and quality. Soils in the southeastren Coastal Plain region exhibit large spatial variability with three distinct horizons; A-horizon (sandy to loamy sand), E-horizon or hardpan layer (yellowish brown sandy to sandy clay), and Bt-horizon (sandy clay loam). Efficient irrigation in these soils are best achieved using site-specific management and system automation via advanced sensors. Multi-sensor capacitance probes are prime candidates for continuous monitoring of soil water status ((Paltineanu and Starr, 1997) and thus automating irrigation scheduling. However, currently there is no published data on the performance of capacitance probes in multi-layer soils of the Coastal Plain region.

Increasing crop water use efficiency (WUE) and use of more drought tolerance cotton varieties also help resource conservation. Screening cotton varieties for WUE would help growers to maintain or increase crop production with less water. Many factors affect WUE at the field scale. It may vary both spatially and temporarily, and is influenced by soil conditions, irrigation water management, agricultural practices, and atmospheric factors. The objectives of this study were to determine the utility of capacitance based moisture probes in irrigation scheduling, examine effective methods for their installation and calibration, and quantify the water use efficiency of several cotton cultivars under a range of irrigation regimes.

MATERIALS AND METHODS

Objective 1 The AquaSpy™ and Sentek EnviroSCAN® multi-sensor capacitance probes were calibrated in a Coastal Plain soil at Clemson University, Edisto Research & Education Center (REC) near Blackville, SC. Sentek probes were used to compare two probe installation techniques. For the "Direct" installation method, a PVC access tube was installed by inserting it through the guide block (Figure 1, left) into the soil using a dry drilling technique explained in Paltineanu and Starr (1997). For the "Slurry" installation method, a hole was drilled using a specially designed auger. The hole diameter was about 6 mm larger than the probe's outside diameter. The slurry (made from the excavated sandy clay loam soil) was poured into the hole (Figure 1, right) and the probe was inserted into the hole with the slurry filling the space between the probe and the hole wall.

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

In 2009, a new probe installation technique was developed based on the 2008 findings. A tractor-mounted, Giddings soil sampling/coring system was used in this study for installing the AquaSpy™ moisture probes. The outside diameter of the coring probe was the same as the outside diameter of the AquaSpy™ probe (6.35cm). A core was taken from the soil to leave a void where the probe was then inserted and "watered-in" to allow the soil to tightly settle around the access tube of the probe.

Several weeks after installation, 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 (Figure 2). This method minimized disturbance of the soil samples. During this process, the soil and probe or access tube interface was examined for air gaps and root growth. 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 probes contain sensors at depths of 10, 20, 30 40, 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.

Figure 2. Calibration trench and ring sampling technique.

The volumetric moisture content (VMC) was determined as the product of soil gravimetric moisture content and bulk density. These values were regressed against the sensor reading to determine the relationships between the two variables.

Objective 2 Tests were conducted in a 2-ha section of a field at Edisto REC.. The test field was equipped with a 76.2 m long linear-move irrigation system (LMIS) modified to apply variable-rate irrigation (VRI) with low energy precision application (LEPA) drops. LEPA drops can increase irrigation efficiency by decreasing wind drift and evaporation (Figure 3). The irrigation system was divided into 10 zones with four drops per zone. Drops were blocked after every three rows to prevent watering in neighbouring plots. The test field was divided into 15.2 by 7.7-m plots containing 8 rows of cotton. Alleys (3m wide) were placed at the end of each section of plots to prevent irrigation overlap.

A commercially available soil electrical conductivity (EC) measurement system (Veris Technologies 3100) 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: DP 0924 B2RF, DP 0920 B2RF, DP 0935 B2RF and DP 0949 B2RF, and
- Four irrigation rates: 0, 30, 60, and 90% of full crop water requirements. This requirement was based on the percentage of total water needed to bring the soil water to field capacity.

Figure 3. Clemson linear-move variable rate LEPA irrigation system.

Cotton varieties were planted on June 2, 2009 and carried to yield using recommended practices for seeding, insect, and weed control. The required irrigation rates were calculated based on the AquaSpy capacitance probes data. With the actual VMC calculated based on the calibration, the VMC readings can be subtracted from the field capacity for each soil layer. Irrigation depth was calculated by adding the depleted water in both soil layers. For each layer, the irrigation requirement (I, mm) was calculated by the following formula:

$$I = \frac{\left[(FC_s - MC_s) * d_s + (FC_c - MC_c) * d_c\right]}{e_i} \qquad (1)$$

Where,

FC_s =Field capacity of sand (0.158 mm^3/mm^3),

MC_s = VMC of 20-30cm depths (mm^3/mm^3),

d_s =Depth of sand and hardpan layers (mm),

FC_c =Field capacity of clay (0.245 mm^3/mm^3),

MC_c = VMC of 40-60cm depths (mm^3/mm^3),

d_s =Depth of clay layer (mm), and

e_i =Irrigation efficiency (0.95 for LEPA system).

The depth measurement taken from each layer of the soil in each zone was averaged to determine the d_s and d_c values. 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.

The field has been susceptible to high runoffs in some areas of the field due to elevation differences. To prevent damage due to runoff from the field throughout the season, a Dammer Diker® (Ag Engineering & Development Company, Tri-Cities, WA) was used in the field. Cotton was harvested on November 9, 2009, using a spindle picker equipped with an AgLeader® yield monitor. Since many upper bolls of DP 0935 cultivar were not open at harvest, these plots were re-harvested in December and seed cotton from these plots was used for calculating the final yield. The WUE was calculated by dividing yield in each plot by the amount of water applied to the plot (water beneficially used). The WUE was also calculated using crop evapotranspiration ($ET_c = ET_o * K_c$). The ET_o was calculated using the Penman-Monteith method (Allen et al.s 1998) with climate data from an on-site NOAA weather station. Crop coefficient (K_c) was locally developed (Bellamy, 2009).

RESULTS AND DISCUSSION

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 4.

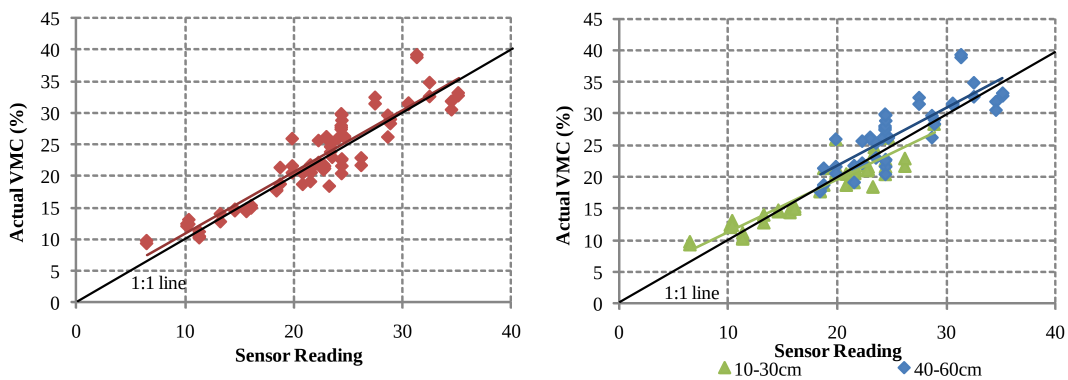
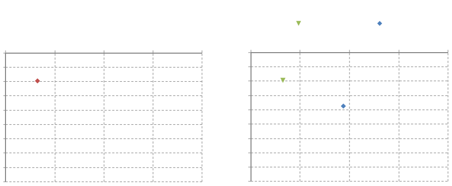


Figure 4. VMC vs. the Sentek sensor readings for all data (left) and two different horizons (right).

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. 2, the slope of the regression line was near unity and the bias was small (about 1.1%).

$$VMC = 0.9861 * SR - 1.0611, \qquad (2)$$

Regression analysis yielded higher correlation for the topsoil (10-30cm) than for the subsoil (40-60cm). The standard error for depths 10-30cm and 40-60cm was 1.8 and 2.82% with R^2 values of 0.873 and 0.680, respectively. This was not expected since the subsoil clay often provided the most accurate readings from previous observations in 2008. The topsoil representing 10-30 cm had a lower range of VMC than the subsoil due to its lower clay content. The hardpan was included in topsoil layer; it contains about the



same composition of the topsoil sand, but a higher bulk density. Using a linear regression analysis, the following equations were obtained for the topsoil sand (subscript s) and the subsoil clay (subscript c) layers, respectively:

$$VMC_s = 0.8304 * SR_s - 2.9992 \qquad (3)$$

$$VMC_c = 0.912 * SR_c - 3.6158 \qquad (4)$$

The regression analysis suggests that the calibration using the Sentek probes can be represented as a single equation (2) for the entire profile with minimal errors.

Figure 5 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).

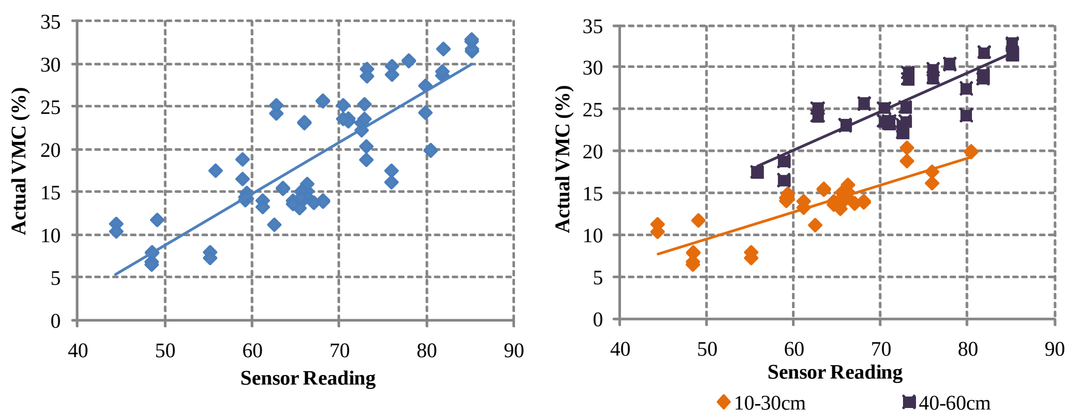


Figure 5. VMC vs. the AquaSpy sensor readings for all data (left) and horizon separation (right).

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:

$$VMC = 0.6033 * SR - 21.372, \qquad (5)$$

The correlations were significantly improved when topsoil and subsoil data were regressed separately. These relationships are given in equations 6 and 7 for topsoil sand and subsoil clay, respectively:

$$VMC_s = 0.3205 * SR_s - 6.4753 \qquad (6)$$

$$VMC_c = 0.4623 * SR_c - 7.5982 \qquad (7)$$

The standard errors for depths 0-30cm and 40-60cm were 1.8 and 2.16% with R^2 values of 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: Table 1 shows the seasonal rain and irrigation applied from planting (2 June) to 30 September for each treatment during 2009. 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. 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. It should be noted that the quantities given below are applied amounts and not necessarily the effective infiltrated depths. Due to runoff and the size of the rain event, the actual depths were probably lower than the values reported in Table 1. During VRI events, runoff was minimized as much as possible by applying irrigation treatments in four separate events, so that application in each event was less than 12.7mm.

Table 1. Seasonal precipitation and irrigation amounts and events in 2009.

Season (June 2 to Sep 30)	Total Rain (mm)	Irrigation			
		90% (mm)	60% (mm)	30% (mm)	Dry land (mm)
	296	311	226	142	57
Total Water	--	607	522	438	353
Total Events	34	13	13	13	13

Figure 6 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 (irrigation plus rain), although this corresponds to the 60% irrigation treatment. Except for DP 0935, yields decreased when more water was applied.

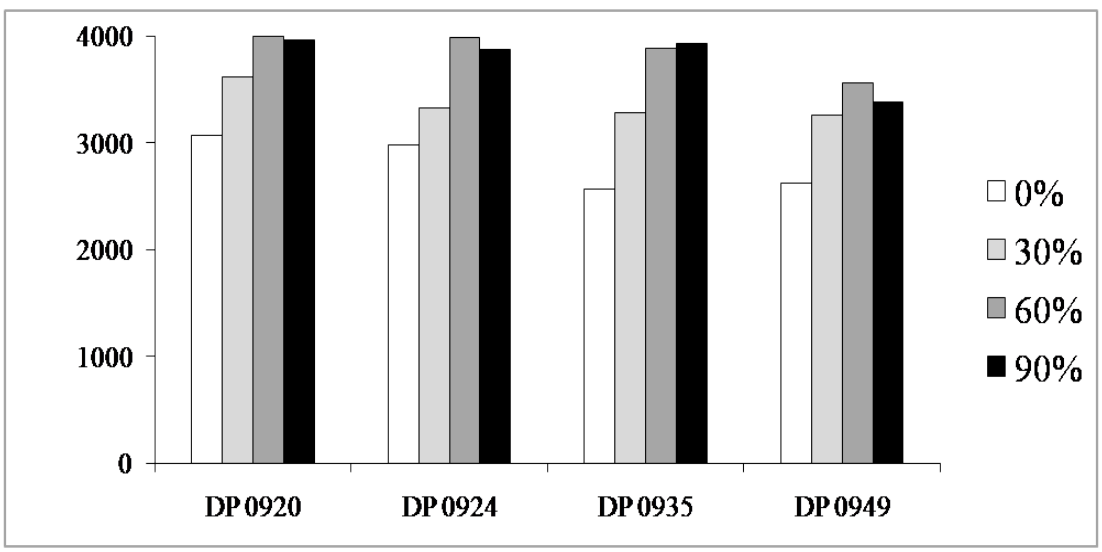


Figure 6. Effects of irrigation treatments on seed cotton yields.

There were significant differences in seed cotton yields among the four cotton varieties as shown in. 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%, Figure 7, right), only DP 0949 yielded significantly less than the other three cultivars. Yield increases above dry land yield for the 60%o irrigation were 931, 1014, 1321and 938 kg/ha for DP0920, 0924, 0935 and 0949, respectively. DP0935 had the highest response to irrigation.

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 plusirrigation) 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.

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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