DEVELOPING AN EFFECTIVE SENSOR-BASED IRRIGATION SCHEDULING TECHNIQUE FOR COTTON PRODUCTION IN COASTAL PLAIN SOILS

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Abstract

Fields in the southeastern coastal plain region have a high degree of variability in soil type and topography, with some areas of the field wetter or dryer than other areas. Efficient irrigation in these fields is best achieved using a sensors-based variable rate irrigation (VRI) system, which takes all of these variations into consideration. However, many cotton growers either don't have access to this technology or don't have the time or comfort level with higher-tech gadgets. Therefore, until VRI systems become simpler for grower use, an efficient and affordable sensor-based irrigation scheduling technique for cotton needs to be developed to account for field variability in the southeastern Coastal Plain soils. Replicated tests were conducted during the 2012-2013 growing seasons to determine: (1) the most accurate and affordable sensor technology; (2) the optimum sensor location in a production field; and (3) the feasibility of using NASA GPS system for irrigation scheduling in cotton production. Our results suggested that, in a production field with soil variability, it would be beneficial to install moisture sensors in management zones with higher soil electrical conductivity (EC) readings to obtain maximum yield and water use efficiency (WUE). Also, we found that NASA's GPS reflectivity technology had poor correlation with actual soil moisture contents and plant stress parameters, possibly due to canopy scattering effects.

Introduction

Sensor-based irrigation is heavily depending on accurate measurement of soil volumetric water contents (VMC). Many different soil-moisture sensors such as TDR, TDT, gypsum block, and multi-sensor capacitance probes are commercially available for measuring VMC (Mathur et al., 2002; Bellamy et al. 2009), which can vary significantly in cost and applicability to practical irrigation management. An important issue, however, is that since these sensors measure soil moisture in discrete locations in a production field, significant number of sensors will be needed for site-specific irrigation management.

Many experiments have shown that microwave band frequencies in the range of 1-3 GHz can be used for soil moisture measurements. This frequency range is ideal for sensing soil moisture contents in a production field due to better penetration of vegetation at longer wavelengths (3 to 12 inches). In addition, the GPS constellation broadcasts a civilian-use carrier signal (L-band) at 1.575 GHz, an optimal frequency for soil moisture remote sensing. Recently, NASA has developed a GPS-based sensor technology that operates by recording the GPS signal reflected from the earth surface (Masters et al., 2004; Katzberg, 2006). A modified GPS Delay Mapping Receiver (DMR) can be used to measure the direct Right-Hand-Circularly Polarized (RHCP) signal of a GPS satellite. The DMR can also simultaneously measures the delayed, earth-reflected, Left-Hand-Circularly Polarized (LHCP) GPS signal. These measurements can be used to estimate the surface reflectivity (dielectric properties) of soil to estimate changes in soil moisture contents.

The overall objectives of this study were to determine: 1) the most accurate and affordable sensor technology for irrigation scheduling; 2) the optimum sensor location in a production field; and 3) the feasibility of using NASA GPS system for irrigation scheduling in cotton production.

Materials and Methods

Optimum Sensor and its Location

To determine optimum sensor and sensor locations in a field, replicated field tests were conducted during the 2012 and 2013 growing seasons at the Edisto Research and Education Center, Clemson University, Blackville, South Carolina. At the initiation of the tests, a commercially available soil electrical conductivity (EC) meter (Veris-3100) was used to identify variations in soil texture across the experimental field. The six-acre test field was then divided into management zones based on soil EC data (4 zones in 2012 and 3 zones in 2013; Figure 1).

Prior to planting, 80 lbs/acre Potash and 1 qt/acre Treflan were incorporated by disking. The test field then was sub-soiled/bedded and 3 gal/acre Telone II was injected for nematode control. The cotton varieties DP 1133 and DP 1050 were planted on June 5, 2012 and May 22, 2013 in all experimental plots, respectively. Cotton was harvested on October 17, 2012 and October 31, 2013, using a spindle picker equipped with an AgLeader yield monitor and a GPS unit to map changes in lint yield within and among treatments to determine the optimum sensor locations.

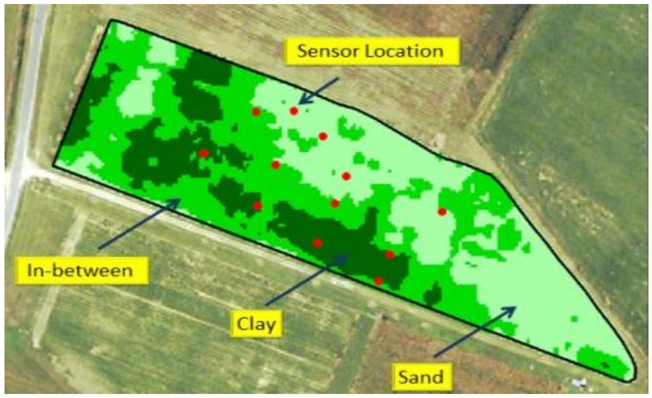

Figure 1. Management zones in 2013

Twenty plots (8-rows by 60 ft) were established in each management zone. There were 5 treatments in 2012 and 4 treatments in 2013. In 2012, the following irrigation treatments were replicated four times in each zone using a randomized complete block experimental design:

- Treatments 1 to 4: irrigation rates calculated based on sensor readings (AquaSpy) from Zones 1 to 4.
- Treatment 5: ET-based irrigation scheduling.

In 2013, the following irrigation treatments were replicated five times in each zone using the same experimental design:

- Treatments 1 to 3: irrigation rates calculated based on sensor readings (Neutron Probe) from Zones 1 to 3.
- Treatment 4: ET-based irrigation scheduling.

Irrigation rates for ET treatment were determined using reference ET (ETo) data obtained from the on-site NOAA weather station (calculated using the Penman-Monteith method) and a locally developed crop coefficient (Kc) curve (Bellamy, 2009 b).

Three sensors were tested in this study, including Decagon EC-5 (Decagon Inc., USA), Watermark 200 SS (Irrometer, USA), and Sentek EasyAg-50 (Sentek Technologies, Australian. The 503 DR Hydroprobe (CPN International, Inc., USA) was used as a reference. In 2012, Watermark and Decagon sensors were installed side by side in the plots of treatments 1 to 4 at three different depths: 8, 14 and 20 inches (84 sensors total). Neutron probe access tubes were also installed adjacent to the other three sensors. Data loggers for watermark and Decagon were installed in the field. The Decagon data logger recorded data at hourly frequency. Watermark sensor readings were recorded when the reading changed at each site and then wirelessly transferred to a receiver located in the center of the field. Data from the receiver was downloaded on a weekly basis. Neutron probe readings were taken weekly at depths of 8 in, 14 in, and 20 in, corresponding to the sensing depth of the Watermark and Decagon Sensors. The required irrigation rates in the test plots were applied using our VRI, LEPA lateral move irrigation system. In 2013, the same procedure was followed. Sentek EasyAg-50 probes were available during September 2013, but were not installed in the field. Both Sentek and Decagon sensors were calibrated against gravimetric moisture content.

NASA GPS system

In 2013, to determine the feasibility of using NASA GPS system for irrigation scheduling in cotton production, the DMR receiver was mounted on Clemson VRI lateral move Irrigation system (Figure 2). Four 25 ft by 50 ft plots were established in the test field. When the GPS system moved over each plot, the device was powered on and collected data for 20 minutes. Geo-referenced soil samples at 4 and 8 inches were taken immediately following data collection with the DMR receiver. Crop stress parameters were also collected at the same time, such as leaf water potential and stomatal conductance. Leaf water potential was measured using a Model 600 Pressure Chamber (PMS Instrument Company, USA). Stomatal conductance samples were collected using a SC-1 Leaf Porometer (Decagon Inc., USA). After sampling, GPS reflectivity data were processed in Matlab using a program developed by NASA to calculate average reflectivity during the 20 minutes sampling cycle in each plot. Linear regressing was used to determine the correlation of reflectivity with actual moisture content and crop stress parameters.

Figure 2. NASA DMR system mounted on Clemson Variable Rate Irrigation System

Results and Discussion

Optimum Sensor and its Location

Calibration results (Figure 3) showed that both Decagon and Sentek sensors could correlate well with actual soil moisture content. However, the slope of Decagon sensors was better (closer to the 1:1 line) than the Sentek sensors.

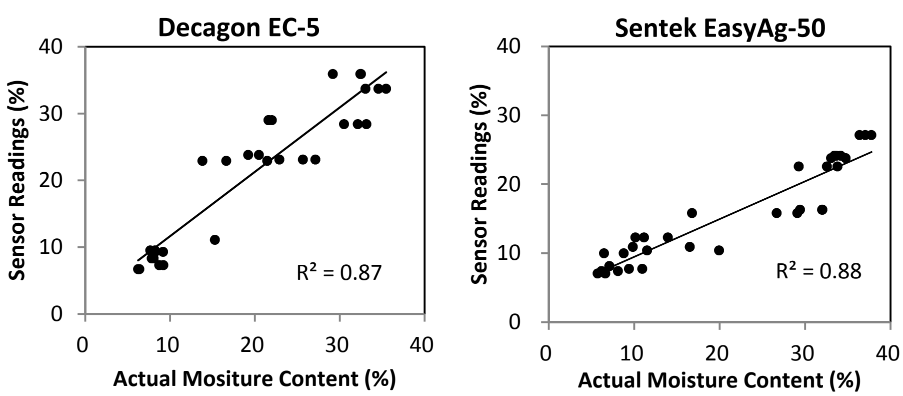

Figure 3. Calibration results of Decagon and Sentek sensors.

Besides calibration, Decagon EC-5 and Watermark 200SS sensor outputs were compared to neutron probe readings in the field to determine the most accurate sensor for irrigation scheduling in cotton production. The original output of Watermark was in centibar (cb) units. To convert cb into volumetric moisture content (VMC), the soil tension curve from Niyazi (2006) was used. Soil tension was converted to VMC as:

$$VMC = -0.054Ln(x) + 0.263 \qquad for\ \ 8''\ depth \qquad (1)$$

$$VMC = -0.0305Ln(x) + 0.3049 \qquad for\ \ 20''\ depth \qquad (2)$$

where x is sensor readings from Watermark 200SS in centibar (cb).

Results showed that the VMC of the Decagon sensor was strongly correlated with neutron-probe's calculated VMC (R^2 = 0.81; Figure 4). VMC of Watermark sensor was correlated with neutron probe's calculated VMC with a lower R^2 of 0.69 (Figure 4). The results suggested that Decagon EC-5 sensor performed better than Watermark Sensor. The cost of Decagon, Sentek, and Watermark sensors, for sensing three depths were $746, $1,000, and $254, respectively. The cost of Decagon sensor was relatively low while provided the best accuracy.

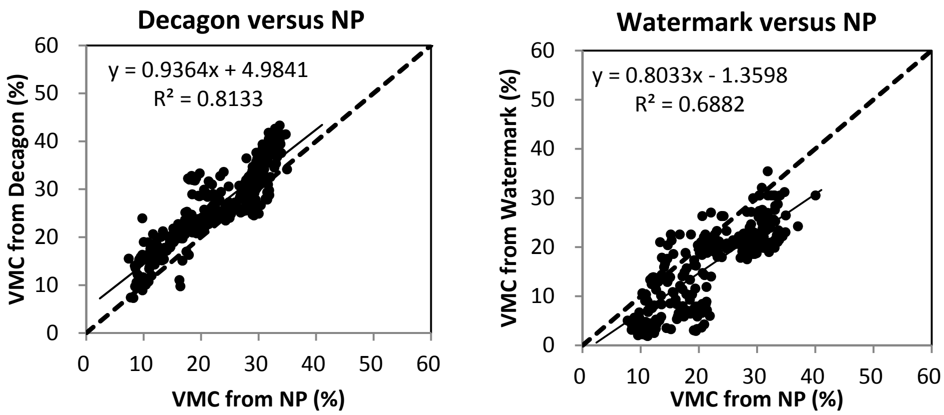

Figure 4. VMC of Decagon and Watermark versus VMC of neutron probe

Total rainfall in 2012 season was 20.2 inches, while in 2013 season it was 22.3 inches. However, total rainfall between planting and first square in the 2013 growing season was 8.6 inches more than during the 2012 growing season. These rainfall events caused intermittent waterlogging in the field and inhibited plant development. As a result, average yield in 2013 (1122 lbs/acre) was significantly lower than yield in 2012 (1857 lbs/acre). Bange et al. (2004) conducted experiments on effect of waterlogging and found that early water logging events during early squaring showed marked impact on reduction of yield compared to late water logging events. Hocking et al. (1987) also pointed out that early flooding impaired uptake of most nutrients by young cotton plants. He also showed that concentrations of P and K were continuously reduced by waterlogging events, which are crucial for cotton development.

The total irrigation applied for the five treatments in 2012 were 4.1, 3.1, 4.2, 4.2, and 2.4 inches, respectively. While, in 2013, total irrigation applied were 2.6, 0.5, 0, and 3.6 inches for the four treatments, respectively. Figure 5 shows the effect of irrigation treatment on cotton lint yields in 2012. Except in Zone 2, Treatment 5 (ET-based irrigation scheduling) yielded significantly lower than the rest of the irrigation treatments. This treatment received 2-inches less water than either Treatments 3 or 4. There were no significant differences in yield between these two treatments (3 and 4) in any of the management zones. Irrigating based on sensors readings in Zone 2 (Treatment 2), had no effects on cotton lint yields in Zone 1 and 2. However, yields in Zone 3 and Zones 4 were significantly reduced when irrigation water was applied based on Treatment 2. Hence, irrigation based on higher EC zones does not have negative effect on cotton lint yield. Average water use efficiency (WUE) was not significantly different between treatments.

In 2013, average yield was not significantly different between treatments. However, as shown in Figure 6, the average WUE of Treatment 2 and Treatment 3 were significantly higher than average WUE of Treatment 1 and Treatment 4. Therefore, irrigation based on higher soil EC zones resulted in significantly higher WUE. Average WUE of Treatment 2 was not significantly different with average WUE of Treatment 3. Also, there was no significant difference in WUE between Treatment 1 and 4.

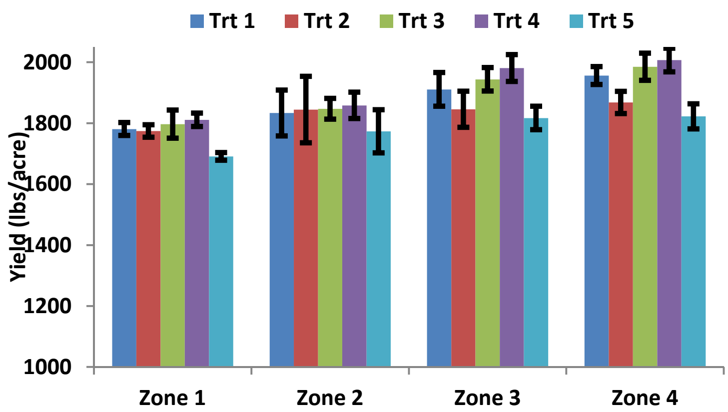

Figure 5. Treatment effect on yield in 2012

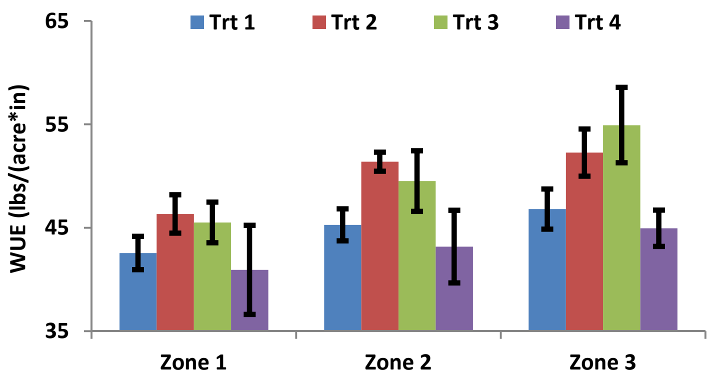

Figure 6. Treatment effect on WUE in 2013

NASA GPS System

Results showed that GPS reflectivity had poor correlation with actual VMC at either 4 inches or 8 inches ($R^2 \leq 0.3$) in the cotton field (Figure 7). Also, GPS reflectivity had no relationship with crop stress parameters, in terms of leaf water potential and stomatal conductance (both $R^2 < 0.1$). However, in a previous study Khalilian et al. (2012) found that GPS reflectivity had strong correlation with actual VMC with a R^2 of 0.75 on bare soils. It was also concluded that ground cover showed defined trend affecting the reflectivity, but it was not statistically significant. The high correlation was possibly due to the condition of the experimental field and crop studied. In their study, the experimental field was either bare soil or covered with wheat. However, cotton is more uneven compared to wheat, which could potentially be a significant source of signal scattering.

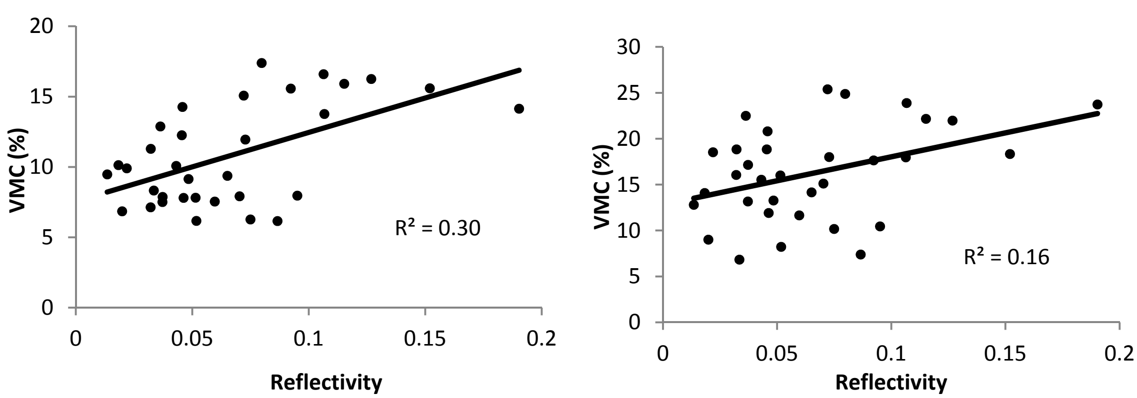

Figure 7. Correlation of GPS reflectivity with real volumetric water content.

Summary

The cost of decagon sensor was relatively low but offered good accuracy. The results also suggested that, in a production field with soil variability, it would be beneficial to install moisture sensors in management zones with higher EC readings to obtain maximum yield and WUE. However, this may not be true during a dry year. From the GPS experiment, GPS reflectivity showed poor correlation with actual soil moisture contents and plant stress parameters, which was possibly due to scattering effect of canopy cover.

Acknowledgements

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