

**WIRELESS SENSOR NETWORK FOR IRRIGATION APPLICATION IN COTTON**

**Ruixiu Sui**  
**Daniel K. Fisher**  
**USDA-ARS**  
**Stoneville, MS**  
**Edward M. Barnes**  
**Cotton Incorporated**  
**Cary, NC**

**Abstract**

A wireless sensor network was deployed in a cotton field to monitor soil water status for irrigation. The network included two systems, a Decagon system and a microcontroller-based system. The Decagon system consists of soil volumetric water-content sensors, wireless data loggers, and a central data station. Sensor data collected by each data logger were wirelessly transferred to and stored in the data station. The microcontroller-based system was designed to be a low-cost data logger for monitoring Watermark water-potential sensors. An infrared thermometer was used in the field to measure plant canopy temperature for evaluating its usefulness in detecting water stress in cotton under humid conditions. Soil water and plant canopy temperature data were collected during the 2011 cotton growing season. Deployment, performance, and maintenance of the systems are described and discussed.

**Introduction**

Uncertainty in the amount and timing of precipitation is one of the most serious risks to producers in the Mid-South, and highly variable soil textural characteristics of the region require careful irrigation planning. In recent years, producers have become increasingly reliant on supplemental irrigation to ensure adequate yields and reduce risks of production, but very few use any irrigation scheduling aids. There is a need to provide technical tools to producers for appropriate management of irrigation in the region.

**Literature Review****Soil Water Sensing**

Timely and accurate determination of temporal and spatial plant and soil water status is essential to proper scheduling of irrigations. In order to increase water use efficiency and productivity, novel sensing technologies are required to determine crop water status and conduct irrigation scheduling. Crop water status and the amount of supplementary water needed can be assessed by measuring soil moisture and plant physical response to water stress. Various types of sensing devices have been developed and made commercially available for water management applications, including sensors for measuring volumetric water content and soil-water potential. Yoder et al. (1997) tested 23 soil water sensors representing eight sensor types, including neutron probe, electrical capacitance sensors, electrical resistance sensors, TDR (time domain reflectometry) devices, and heat dissipation sensors with carefully controlled soil water contents. Measurement errors of the volumetric water content of the soil were determined for each sensor. The results indicated that the capacitance sensors had the best performance in the study. Leib et al. (2003) evaluated soil moisture sensors of several different brands and types under identical operating conditions in the field for three years. They found that most sensors were able to follow the general trends of soil water or potential changes during the growing season, but that actual measured values varied significantly between sensors and calibrated neutron probe measurements. It was suggested that a soil specific calibration of each sensor was necessary to obtain high accuracy in the measurements. Evett et al. (2006) compared several EM (electromagnetic) sensors with a neutron moisture meter in measuring water content of three soils. It was found that all EM sensing devices exhibited estimation precision better than  $0.01 \text{ m}^3 \text{ m}^{-3}$  under isothermal conditions. However, under non-isothermal conditions the test showed that all of them were sensitive to soil temperature differences. Similar to the suggestion by Leib et al. (2003), the authors recommended that all of the EM sensing devices would require separate calibrations for different soil horizons. Previous research indicated that the EM sensors were inexpensive, easy to install and maintain, and able to provide reliable information for irrigation scheduling and control. However, the sensors must be well-calibrated under specific operation conditions including soil type and temperature.

### **Automated Data Acquisition**

Rapid advances in electronic technology have resulted in a variety of new sensing, monitoring, and control capabilities. These current and rapidly evolving technologies can be adapted to provide the high level of monitoring and control capability that is needed to address information requirements for agriculture and water management. While many different types of data-collection instruments and sensors are currently commercially available, features, capabilities, and prices can vary greatly. Many data acquisition and data logging systems are commercially available, and can be deployed relatively quickly and easily. Inexpensive solid-state sensors, microcontrollers, and auxiliary components are also available for use in developing inexpensive, custom-designed monitoring systems (Moody et al, 2004; Noordin et al., 2006; Fisher, 2007; Vellidis et al., 2008; Fisher and Kebede, 2010).

Wireless sensor network (WSN) offers the capability of providing continuous, real-time, in-situ measurements under a variety of operating conditions. Recent advances in WSN and internet communication technologies offer tremendous opportunities for development and application of sensor systems for agriculture (Wang et al., 2006; Pierce and Elliott, 2008; Kitchen, 2008). Research has been conducted on using wireless systems for irrigation scheduling and automation (Harms, 2005; King et al., 2005; Pierce and Elliott, 2008; Lea-Cox et al., 2009). Kim et al. (2009) integrated a controllable irrigation system with WSN for automated variable-rate irrigation in which soil moisture sensors installed in the field were remotely monitored by a base station, allowing irrigation decisions to be made site-specifically. Vellidis et al. (2008) developed and evaluated a wireless smart sensor array for irrigation scheduling in cotton. The wireless sensor system monitored soil water status and soil and air temperature during the growing season, and data collected by the system were successfully used for scheduling irrigation. O'Shaughnessy and Evett (2010) compared the performance of mesh and non-mesh WSN located on a center pivot lateral and in the irrigated field below the center pivot system and observed that wireless mesh-networking sensors could function on a moving sprinkler irrigation system. Expanding cellular communications infrastructure is further increasing data-transmission options, making monitoring from very remote locations possible and affordable. Cellular communications, in conjunction with the Internet, are revolutionizing the transmission of and access to information.

### **Objectives**

The objectives of this study were to 1) develop a method for installation and maintenance of a wireless sensor system for soil moisture measurement, 2) conduct field evaluation of the performance of the soil sensor measurement system; and 3) measure plant canopy temperature in a cotton field.

## **Materials and Methods**

### **Experimental site**

A 10-ha cotton field at the USDA Agricultural Research Service's Jamie Whitten Delta States Research Center at Stoneville, MS (latitude: 33°26'30.86", longitude: -90°53'26.60") was selected as an experimental site. Soil texture of the field varied from very sandy silt loam to silty clay loam. The field was split into irrigated and non-irrigated treatments based on a map of soil electrical conductivity (EC). Within each treatment plots were laid out in a complete randomized block design (CRBD) with six nitrogen (N) application rates (0, 39, 67, 101, 135, and 168 kg/ha) and four replications.

### **System Description**

Two systems were used to measure and record soil water status, one consisting of sensors and data loggers from Decagon Devices, and the other using Watermark sensors and microcontroller-based data acquisition unit. Infrared thermometers were used to measure plant canopy temperature in the field.

### **Decagon System**

Decagon systems used in this study include soil water-content sensors, wireless data loggers, and a wireless data station (Decagon Devices, Inc., Pullman, WA). Two types of soil water-content sensor were used; models EC-5 and 5TM. The EC-5 sensor measured soil volumetric water content only while the 5TM sensor measured both the water content and soil temperature. EM50R and EM50G data loggers were used to collect data from the sensors. The EM50R is a radio data logger, which is able to wirelessly transmit data to the data station at 900MHz and has a 1 Megabytes of memory for data storage. The EM50G logger transmitted data through a cellular communication network. Decagon provided the service to make the data wirelessly received from the EM50G logger available on the internet. Each data logger (EM50R and EM50G) could collect data from up to 5 sensors. The data station was

employed to receive and store the data that were sent by EM50R loggers. Data stored in the data station were downloaded in the field via its serial port to a laptop computer for processing.

### **Microcontroller-based System**

The microcontroller-based system consists of a microcontroller-based data logger and three Watermark 200SS matric-potential sensors (Irrometer Company, Riverside, CA USA). The data logger was based on an PIC16F819 microcontroller (Microchip Technologies, Inc., Chandler, AZ). Circuitry included a real-time clock/calendar chip for time-stamping sensor data, an alternating-current circuit for reading the soil-moisture sensors and a non-volatile memory chip for data storage. The microcontroller was designed and programmed to enable long-term, battery-powered operation by spending most of its time in a low-power, sleep mode. Periodically, the microcontroller would wake up and read the current time from the real-time clock. If it was time to take a measurement, power was sent to the measurement circuit, otherwise the microcontroller returned to sleep mode. At one-hour intervals, the measurement circuit was enabled, the three soil-moisture sensors were read, and data were stored to the memory chip. A more detailed description of the data logger and its fabrication and operation are provided by Fisher (2007).

### **Infrared Thermometer**

The infrared thermometer (IRT) was a research prototype which includes a data logger and temperature sensors (Fisher and Kebede, 2010). The data logger consists of a PIC16F88 microcontroller (Microchip Technologies, Inc., Chandler, AZ), real-time clock/calendar and memory chips, and circuitry for interfacing and reading sensors. Two sensor measurements were collected; air temperature, measured with an LM35 analog temperature sensor (National Semiconductor, Santa Clara, CA), and IRT canopy temperature, measured with an MLX90614 IRT module (Melexis SA, Ieper, Belgium). Measurements were collected and stored to the data logger's memory chip at one-hour intervals, and were downloaded during periodic visits to a handheld computer.

## **System Installation and Data Collection**

### **Decagon System**

Ten Decagon systems, including nine EM50R data loggers and one EM50G logger, were deployed at ten locations of the selected cotton field. The locations were chosen based on the EC map of the field to include a wide range of soil types to examine the effect of soil type on soil water sensor performance. One Decagon system was installed at each of the ten locations while a microcontroller system was installed along with the Decagon system in four locations. Three soil volumetric water-content sensors were installed at each location. To install the sensor, a bracket was made using 7.6-cm diameter PVC pipe (Figure 1). Three windows at 15, 30, and 60cm from the top of the bracket were cut for inserting the sensors into the soil. A hole at the center of crop row was drilled using a soil auger. The PVC bracket was placed into the hole with its top surface horizontally aligned with ground surface, and the window side of the bracket was installed against the wall of the hole. Then the sensors were horizontally inserted into the soil through the windows. The EC-5 sensor was installed in the depths of 15 and 60cm while the 5TM sensor in 30cm depth. Sensor cables were pulled out through the PVC bracket, and the hole was filled with soil. The data loggers were mounted on a pole, which was made out of a 7.6-cm diameter PVC pipe with a height of 1.8m. The sensors underground were connected to the logger by plugging sensor outputs to logger's inputs. A PVC coupler was used to join the underground bracket and the PVC pole above the ground (Figure 1). The coupler was used to easily lay down the logger to prevent damage from equipments used in field operations during the crop growing season.

Data from the sensors were continuously and automatically collected at a time interval of one hour by each radio data logger and wirelessly transmitted to and recorded by the data station. Data collected by the EM50G cellular data logger were downloaded to a computer in lab after accessing the data via the internet. The data station located at the edge of the field was powered by a solar panel.

### **Microcontroller-Based System**

Watermark water-potential sensors were installed at three depths, 15, 30, and 60cm below the soil surface, which was consistent with the Decagon system. Sensors were attached to a 2.5cm diameter PVC pipe and a soil sampler was used to drill holes at the center of the crop row for inserting the sensors. After placing the sensor to a desired depth, the hole was filled and packed with soil to make the sensor well-surrounded by the soil. The sensors were connected to a data logger, which was placed inside a weatherproof plastic enclosure attached to a wooden stake driven into the ground (Figure 1). Periodically throughout the growing season, each site was visited to download

data from the memory chip to a portable computer. The data, in standard ASCII text format, were then returned to the office, uploaded to a desktop computer, and input to a spreadsheet for viewing and analysis.



Figure 1. Show installation of soil moisture sensors, data loggers, and the data station.

### **Infrared Thermometer**

Infrared thermometer sensors were mounted inside thick-walled PVC plastic enclosures and installed in the field, as shown in Figure 2. Cotton rows ran east and west, and the sensors were oriented facing north, aimed at the south-facing, sunlit leaves of the crop. The sensors were installed at four sites, two in irrigated plots and two in non-irrigated plots. Soil in this field consisted of two predominant types, a very fine sandy loam and a silty clay loam, with an irrigated and non-irrigated plot located in each soil.





Figure 2. Infrared thermometer measuring cotton plant canopy temperature.

#### **Field Management**

Cotton (DP 0912 B2RF) was planted on May 8, 2011. Nitrogen was variably applied to each plot in the range of 0 to 168 kg/ha using a side knife drill on June 24, 2011. Irrigation water was applied to alternate furrows using a poly-pipe system. The irrigated plots were irrigated twice during the season: 5cm water was applied on July 6, 2011 and 7.6cm on July 20, 2011. Non-irrigated plots were defoliated on September 8, 2011 and irrigated plots on September 23, 2011. Cotton was machine harvested with spindle-type picker on October 11, 2011. Seed cotton from the center 12 center-rows of each 24-row plot were transferred to a load cell-equipped boll buggy and weighted for yield estimation.

#### **Results and Discussion**

Soil moisture and soil temperature data were measured and recorded using the Decagon and microcontroller-based systems during 2011 cotton growing season. In general the sensor systems performed well under normal operation conditions. Data collected followed the trends of soil water change during growing season and could be used for irrigation scheduling. As an example, Figure 3 showed the soil water content and soil temperature measurements by the Decagon system in one location. The sensors responded to irrigation and rainfall events. In the early season the plant used the water mainly in the top layer of the soil. As plants grew and roots expended, they absorbed more water from deeper soil, the soil water content at greater depths decreased, as the readings from the sensors at 30 and 60cm depths indicated. After defoliation, the plant lost leaves and used less water. Soil water content restored to a higher level (Figure 3). Due to new firmware installation, there was no data collected by this logger from July 1 to July 10, 2011.

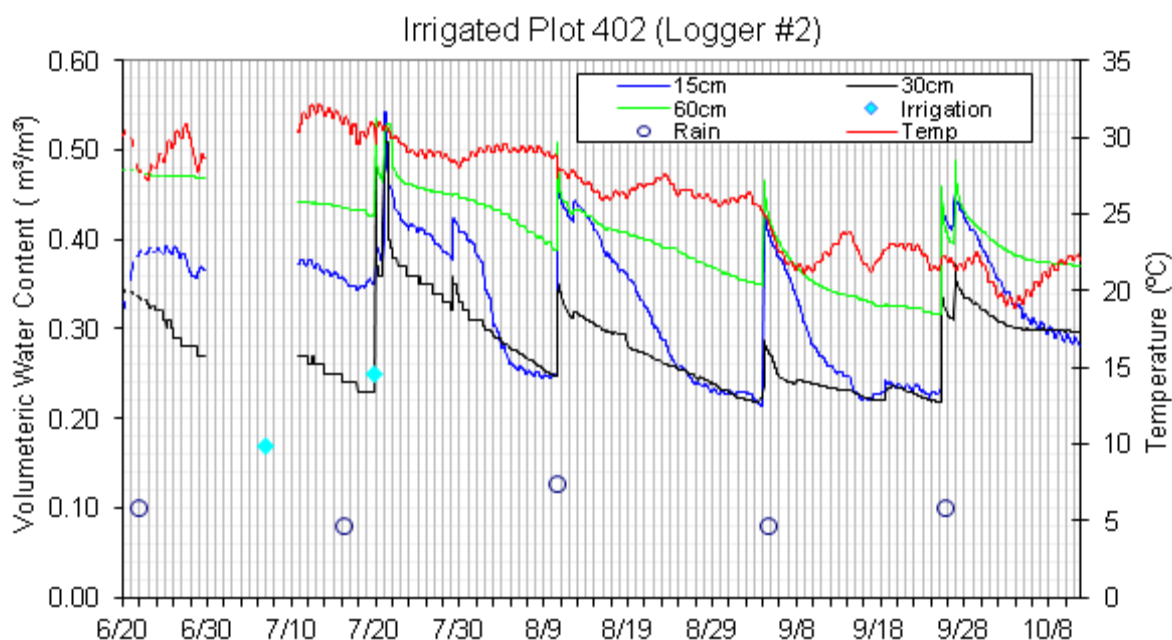


Figure 3. Graph of soil water content and soil temperature measured in the cotton field during 2011 season using Decagon system.

Hourly data showing Watermark soil-water potential measurements and Decagon volumetric water-content measurements are shown in Figure 4. The numerical data from the two different sensor types could not be related directly due to the different physical soil parameters measured. They could, however, be compared qualitatively by observing the general trends in the measurements over time. At each depth, the corresponding sensors appeared to show consistent behavior, reacting to the changing conditions at each depth in the soil profile. Lower (more negative) soil-water potential readings at the 15 and 60cm depths indicated that soil water was less available than at the 30cm depth, but steadily changing values suggested that the plants were able to access the moisture at all levels. Around August 8, behavior of the 30cm sensors suggested that roots at this depth may have begun to reduce water-use: water-potential readings began to decrease more rapidly, while water-content readings stopped decreasing.

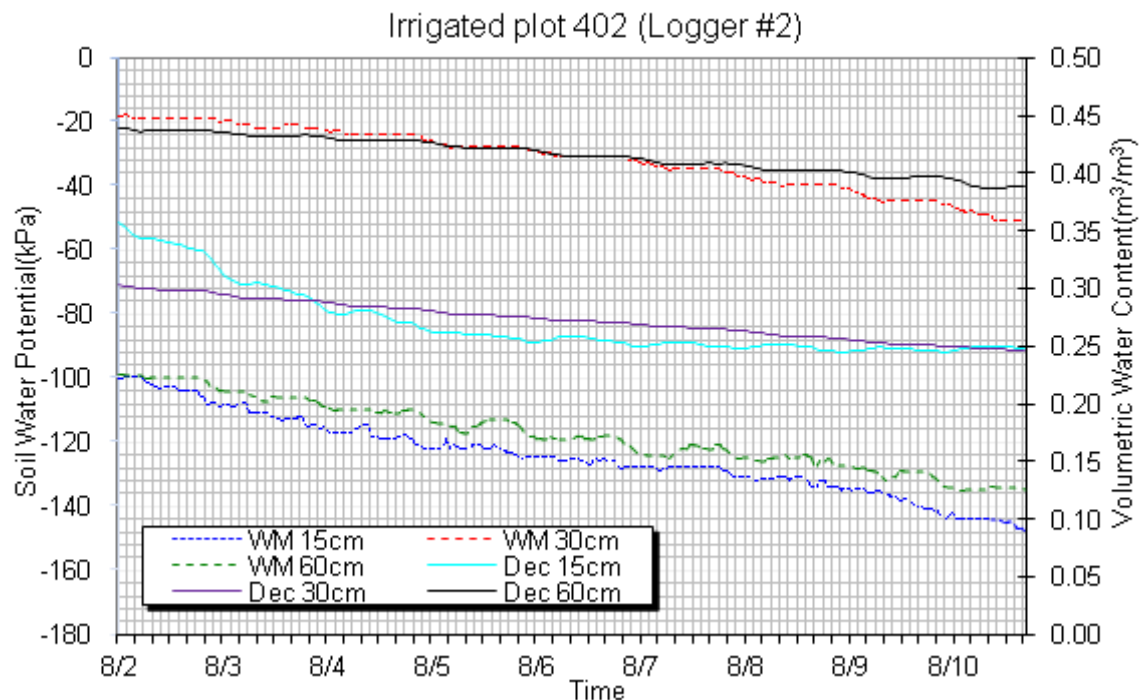


Figure 4. Comparing soil water content measured by Decagon system using Decagon sensor (referred to as Dec.) with soil water potential measured by the microcontroller-based system using WaterMark sensor (referred to as WM).

The Decagon system was programmed to use a calibration algorithm provided by the manufacture. Since this was a new measurement system, the intent was to install the sensors and ensure that the data loggers and wireless and cellular communications operated properly. No sensor calibration work was done to verify or modify the manufacturer's calibration equations for local soil characteristics. The system might need to be recalibrated for local conditions since different soil properties could have different effects on the sensor's response to soil water content.

Hourly canopy-temperature measurements during a five-day period in August-September 2011 are shown in Figure 5. Canopy temperatures were higher in the non-irrigated plots, with temperatures 2-4 °C higher than in the irrigated plots during the peak time of the day. In both the irrigated and non-irrigated plots, temperatures were slightly higher in plants growing in the silty clay loam soil compared to those in very fine sandy loam.

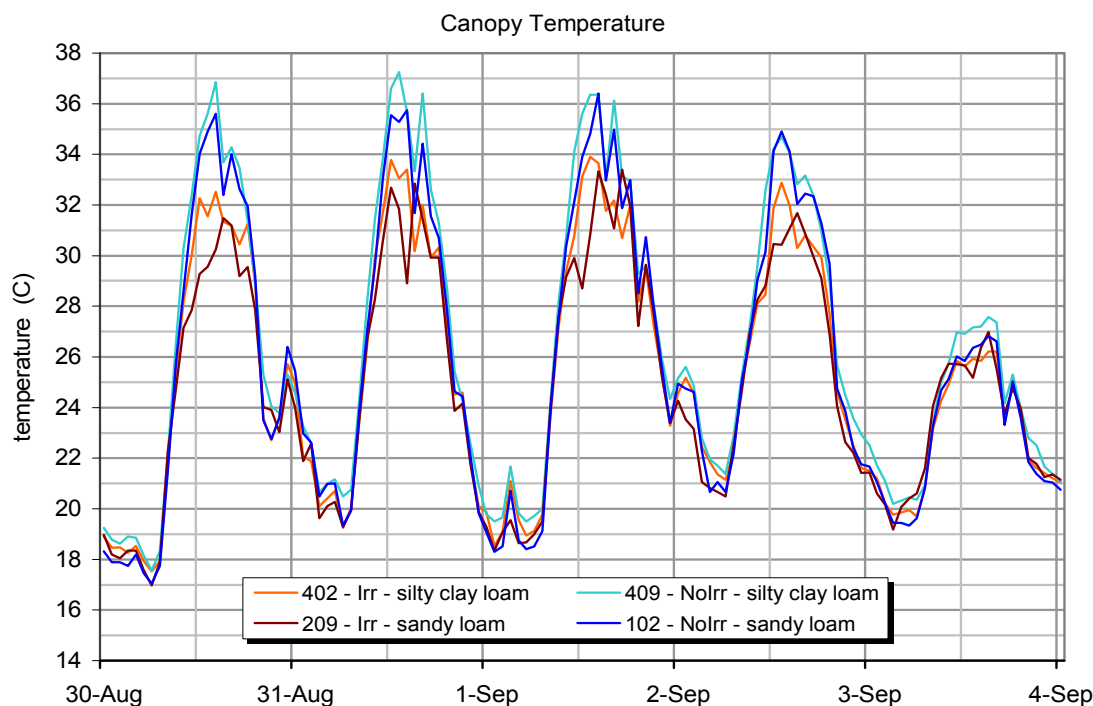


Figure 5. Canopy temperatures measured using the Infrared Thermometer.

Average yield of non-irrigated plots was 2976 kg/ha seed cotton. Yield of irrigated plots was 3339 kg/ha, which was 12% higher than that of the non-irrigated. Irrigation made significant increase of cotton yield in year 2011 in this study.

A few issues affecting the performance of the monitoring system were observed during field operation of the Decagon wireless systems: 1) battery inside the data logger become loose and lost connection, causing the data logger to stop collecting data, 2) a sensor cable was damaged by wild animals in the field, 3) Decagon sensors could be damaged as they were being pushed to insert into hard soil, and 4) data loggers were occasionally knocked down by field equipments such as sprayers. Attention must be given to resolve the issues for successful application of the wireless system in agriculture field.

### Conclusions

For studies on irrigation scheduling, a wireless sensor network system and a microcontroller-based system were deployed to measure soil water and soil temperature in a cotton field. And plant canopy temperature of the field was also measured using infrared thermometer. Procedures for installation and maintenance of the soil water measurement systems were developed and field evaluated. Results indicated that the soil water sensors were able to measure the soil water status, and the measurements recorded by the systems reflected general trends of soil water change during the growing season. Canopy temperature of non-irrigated plant is 2-4 C higher than that of the irrigated plant during peak time of day. Irrigated plots increased cotton yield by 12% compared with the non-irrigated. System installation and maintenance procedures developed worked well in general. However, some installation and operational issues were found and need to be resolved for field operation and user acceptance.

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### **Disclaimer**

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