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Use of Soil Moisture Sensors for Irrigation Scheduling

Ruixiu Sui

USDA-ARS Crop Production Systems Research Unit, Stoneville, Mississippi, USA

Abstract. *Soil moisture sensors were evaluated and used for irrigation scheduling in humid region. Soil moisture sensors were installed in soil at depths of 15cm, 30cm, and 61cm belowground. Soil volumetric water content was automatically measured by the sensors in a time interval of an hour during the crop growing season. Soil moisture data were wirelessly transferred onto internet through a wireless sensor network (WSN) so that the data could be remotely accessed online. Soil water content measured at the 3 depths were interpreted using a weighted average method to reflect the status of soil water in plant root zone. A threshold to trigger an irrigation event was determined with sensor-measured soil water content. An antenna mounting device was developed for operation of the WSN. Using the antenna mounting device, the soil moisture measurement was not be interrupted by crop field management practices. The soil moisture sensor-based irrigation scheduling method has been used for irrigation scheduling in a USDA-ARS Research Farm in Stoneville, MS.*

Keywords. Soil moisture sensor, irrigation scheduling, wireless sensor

Introduction

The Mid-South region is a major area for crop production in the United States. The main crops grown in the region are soybean, corn, cotton, and rice. Though annual precipitation in the Mid-South is approximately 1300 mm, only about 18% of the precipitation occurs during June to August when crops require a large quantity of water to grow. Furthermore, changes in precipitation patterns have made both drought and excessive rainfall more frequent (UCS, 2011; Earth Gauge, 2011). Heavy rainfall causes extensive amounts of runoff from cropland, resulting in only a small amount of the precipitation infiltrating into the soil for crop use. Uncertainty in the amount and timing of precipitation is one of the most serious risks to crop production in the region. To reduce the risk and increase farming profit, the producers increasingly pump large amounts of groundwater from Mississippi River Valley alluvial aquifer each year to irrigate crops during the growing season (Vories and Evett, 2010). Due to the large withdrawals from the aquifer, groundwater levels in the region have declined significantly. Common method used in irrigation scheduling in this region is based on visual assessment of crop response and a “feel” for soil water status. There is a great need for the producers to have objective, reliable, and easy-to-use water management technologies that work for the Mid-South crop/soil environments.

Irrigation scheduling determines the time and amount of water to apply. One of the most popular methods for irrigation scheduling is to measure soil moisture levels in the plant root zone and apply water if there is water shortage for plants. Soil moisture content can be directly determined using manual gravimetric soil sampling by weighing and drying the soil sample. The gravimetric method is simple. However, it is time consuming and expensive as frequent measurements are required. Soil moisture sensors are able to measure soil moisture content indirectly. In recent years, various types of soil moisture sensing devices have been developed and made commercially available for water management applications. Some of these devices are capable of wirelessly transferring the data collected from their sensors.

Evaluations have shown that each type of the sensing devices has its advantages and shortcomings in terms of accuracy, reliability, and cost (Basinger et al., 2003; Chanzy et al., 1998; Evett and Parkin, 2005; Seyfried and Murdock, 2004; Yao et al., 2004). The neutron probe has been shown to be a reliable tool for determining soil water content. However, its use of radioactive source, the maintenance requirement, and the cost have restricted its application in recent years. Meanwhile, electromagnetic (EM) sensors, such as electrical capacitance and resistance type sensors, and time-domain reflectometer (TDR) devices have been rapidly developed and adopted for soil-water measurement (Dukes and Scholberg, 2004; Fares and Alva, 2000; Miranda et al., 2005; Seyfried and Murdock, 2001; Vellidis et al., 2008). Previous research indicated that the EM sensors could be useful tools to determine soil moisture status. However, the sensors must be well-calibrated under specific operation conditions including soil type and temperature (Yoder et al., 1997; Leib et al., 2003; Evett et al., 2006; Sui et al., 2013).

The objective of this study was to develop a practical method to use soil moisture sensor for irrigation scheduling in humid region.

Procedures

Site and Devices. Soil moisture sensing system was implemented at a Research Farm of USDA-ARS Crop Production Systems Research Unit at Stoneville, MS. The system included soil volumetric water content sensors (EC5, GS1, Decagon Devices, Pullman, WA), two models of data loggers (Em50R and Em50G, Decagon Devices) and a data station (ECH2O 900 MHz, Decagon Devices) for data acquisition, and a measurement and control data logger (MCDL) (CR1000, Campbell Scientific, Logan, UT) coupled with a wireless modem (RavenXTG, Sierra Wireless, Carlsbad, CA) for data collection and transmission. An omni-directional antenna was selected to work with the modem. The antenna was mounted on the top of a 3-m tower. The data station, MCDL, and wireless modem were housed together in a water-proof fiberglass box. Em50G and Em50R data loggers used batteries for power supply while the data station and MCDL were powered by a solar power supply (Sui and Baggard, 2015). The system were installed across three fields under coverage of a center pivot irrigation system (Figure 1). The soil type of the fields varied from silt to silt loam. Cotton, corn, and soybean crops were grown in the fields. Field size was approximately 7.5, 6.6, and 6.6 ha for cotton, corn, and soybean, respectively. In growing season of 2015 and 2016, six Em50G loggers were installed in cotton field, while five Em50R and one Em50G in corn field, and five Em50R and one Em50G in soybean field. Soil types were considered in selecting locations to install the sensors. Since soil type relates to soil EC, EC maps of the fields were used to identify the sensing locations in the three fields. At least one sensing location was chosen for each soil type so that the soil-water variability within a field could be observed.

EC5 and GS1 sensors were used with the data logger Em50R and Em50G to measure soil volumetric water content. The Em50R logger used a 900-MHz frequency radio to transmit data to the data station. After the data were automatically downloaded from the data station to the MCDL, the wireless modem automatically transmitted all data through a commercial wireless network to make the data accessible on the internet using a LoggerNet data logger support software (Campbell Scientific, Logan, UT). In the Em50G logger system, data were transmitted through a cellular communication network to a service which made data available on the internet. A software form Decagon was used to download the data and display the soil moisture graphics. Both Em50G and Em50R logger had the capacity to collect data from up to 5 sensors. In this study three soil moisture sensors were used with one data logger.

Sensor Calibration. The EC5 sensors were tested with various Mississippi soils. Six 183cm x 183cm x 71cm wooden compartments were built inside a greenhouse, and each compartment was filled with one type of soil from the Mississippi Delta. The sensors with the data loggers were installed in the soil compartments to measure soil water content. Using a sprinkler water was applied to the soils. Soil samples were periodically collected from the compartments to determine the soil water content using gravimetric method. The soil water content measured by the sensor readings were compared with the soil water content determined by the gravimetric method for sensor calibration.

The sensors were also evaluated using another weighing method. Five 2-Gallon pots were filled with the soil from the field where the sensors were installed. Dry matter and bulk density of the soil in the pot was determined. One EC5 sensor was installed in each pot. After the pot was saturated with water, the pot with the sensor was placed on an electronic scale to continuously measure the weight. Meanwhile, the sensor measured the soil water content. Soil water content in the pot was calculated using the scale-measured weight and the known soil dry matter and bulk density. Scale-measured water content was then compared with the sensor-measured water content for the calibration.

Sensor and logger Installation. The sensors were installed at depths of 15cm, 30cm, and 61cm, respectively. To install the sensors, a hole was drilled at the center of the crop row using a soil auger. The soil moisture sensors were inserted horizontally into the soil at the designated depths. All Em50R and Em50G data loggers were set up to continuously make one measurement of soil water content in every minute and calculated the hourly average of the measurement. Then, the readings of soil water content were wirelessly transmitted to the data station at a time interval of one hour.

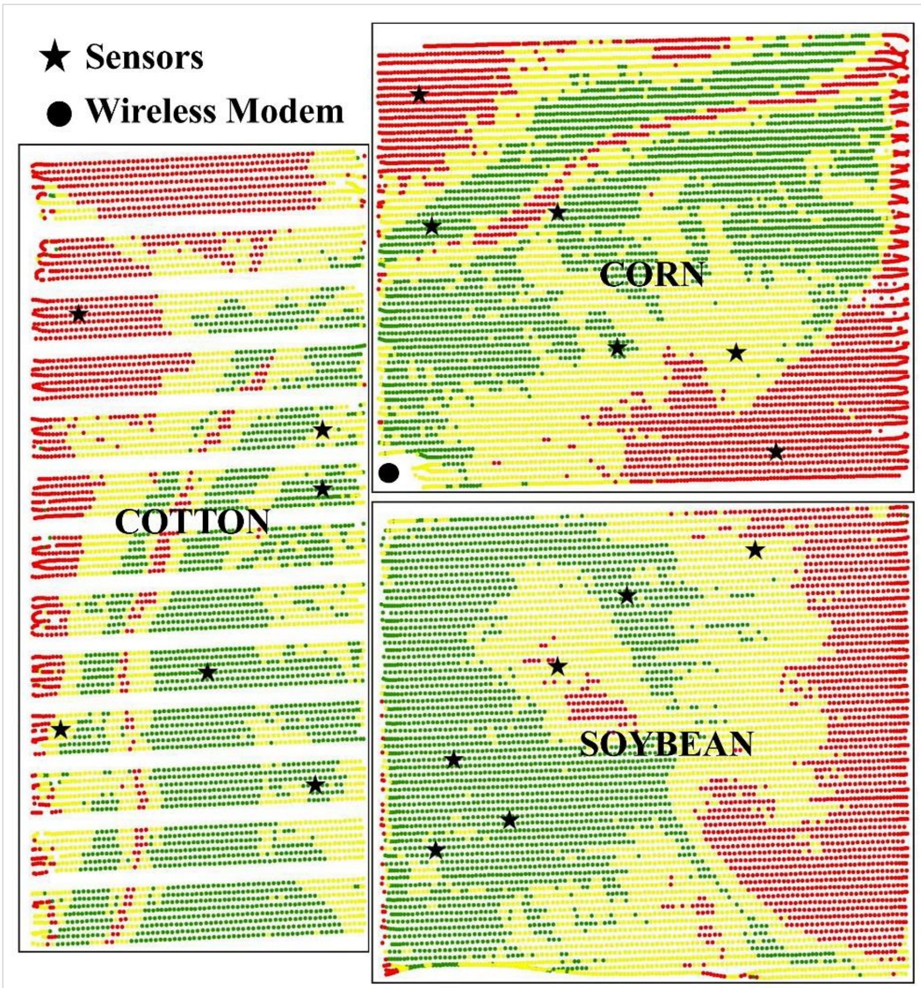

Figure 1. Field layout of the soil moisture sensors. The background is soil electric conductivity maps.

It was found that data transmission of Em50R logger was affected by plant canopy. Data could not properly transmitted when plant canopy was higher than the antenna of Em50R logger. To use a pole to place the antenna to a higher position could eliminate this issue. However, the antenna poles in field will obstruct normal operation of the equipment such as sprayers. To make the wireless sensor more practical for field use, an antenna mount was developed for Em50R data logger. The antenna mount includes a spring, a U-shaped metal base, and a PVC pipe. The spring was mounted between the center of the base and one end of the pipe. A hole was drilled in the pipe at about 30cm from the spring-pipe joint for pulling antenna cable inside the pipe for cable protection. The antenna connected to the cable was installed inside the top end of the pipe. In use of the mount in field, the U-shaped base was inserted into the soil, and the antenna cable was connected to the wireless device (Figure 2). As the agricultural equipment passed over the wireless device and impacted the PVC pipe, the spring in the mount would be bent and the antenna inside the PVC pipe would be protected from damage (Sui and Baggard, 2015).

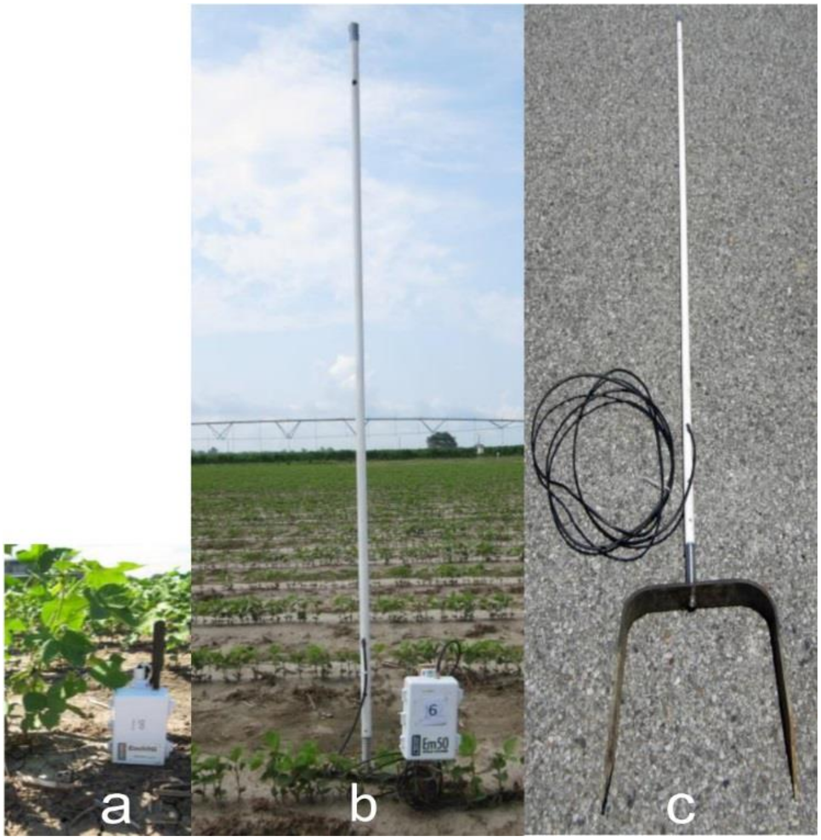

Figure 2. (a) Em50G logger installed in cotton field; (b) Em50R logger with the antenna mount in soybean field; (c) Antenna mount.

Results and Discussion

Sensor Calibration. Readings from the sensors have a linear correlation with the gravimetric soil water content. The sensors over-estimated the water content when the manufacture's "mineral soil" calibration was used. The sensors were capable of detecting general trend of soil-water changes. However, their measurements varied among the sensors and were influenced by soil texture. To obtain accurate measurements, the sensors require soil-specific calibration.

Data Processing and Application. Soil water content measured at the 3 depths were interpreted using a weighted average method to better reflect the status of soil-water in plant root zone. Weighted average of soil water content was used for irrigation scheduling. A weight was assigned to each sensor measurement based on the sensor depth. The weighted average measured by the sensors at 48 hours after the soil is saturated was used as sensor-measured field capacity (FC). Irrigation was triggered when soil moisture content was dropped close to the level approximately 50% of plant available water.

This soil moisture sensor-based irrigation scheduling method has been used in cotton, corn, and soybean crops. In general, it worked fairly well. However, it has been observed that the weights assigned to the measurement at different depths and the threshold to trigger an irrigation event should be adjusted according to crop type and crop growth stages due to the difference of crop root distribution patterns in the soil profile.

Installation and maintenance. The sensor installation and maintenance are critical in application of soil moisture sensors. The sensors should be installed in a representative area of the field. In installation, it needs to make the sensor prongs contact the soil well, and minimize the disturbance of the soil profile. The sensor should be installed on crop row and the plants near the sensing location should not be damaged during sensor installation and maintenance. After growing season, the loggers can be disconnected from the sensors and removed from field. The sensor can remain in the soil for use in next season. However, attention should be given to prevent the sensor from being damaged in field practices such as subsoil tillage. The section of sensor cable above the ground could be damaged by wild animals in field. It needs to be protected using physical or chemical means (e.g., flexible aluminum conduit or spray).

Conclusion

The soil moisture sensors were evaluated for use in irrigation scheduling in a humid region. The sensors with wireless data loggers were able to monitor soil-water status, and the sensor measurements could be used as a guidance for irrigation scheduling. For better results, the sensors require the calibration with soils from the field where the sensors will be installed. In one sensing location, it was suggested to install 3 sensors at different depths across crop root zone. Crop root distributions across the root zone and crop growth stages should be considered when the sensor readings at different measurement depths are used to determine a threshold to trigger irrigation events.

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References

Basinger, J.M., G.J. Kluitenberg, J.M. Ham, J.M. Frank, P.L. Barnes, and M.B. Kirkham. 2003. Laboratory evaluation of the dual-probe heat pulse method for measuring soil water content. Vadose Zone J., 2:389–399.

Chanzy, A., J. Chadoeuf, J.C. Gaudu, D. Mohrath, G. Richard, and L. Bruckler. 1998. Soil moisture monitoring at the field scale using automatic capacitance probes. Eur. J. Soil Sci., 49:637–648.

Dukes, M.D. and J.M. Scholberg. 2004. Soil moisture controlled subsurface drip irrigation on sandy soils. Applied Engineering in Agriculture, 21(1):89-101.

Earth Gauge. 2011. http://www.earthgauge.net/wp-content/fact_sheets/CF_Drought.pdf. Accessed in May 28, 2011.

Evett, S.R., and G.W. Parkin. 2005. Advances in soil water content sensing: The continuing maturation of technology and theory, Vadose Zone J., 4:986–991, doi:10.2136/vzj2005.0099.

Evett, S.R., J.A. Tolk, and T.A. Howell. 2006. Soil profile water content determination: sensor accuracy, axial response, calibration, temperature dependence, and precision. Vadose Zone J., 5:894-907

Fares, A. and A.K. Alva. 2000. Evaluation of capacitance probes for optimal irrigation of citrus through soil moisture monitoring in an entisol profile. Irrig. Sci., 19:57-64

Leib, B.G., J.D. Jabro, G.R. Matthews. 2003. Field evaluation and performance comparison of soil moisture sensors. Soil Science, 168(6):396-408.

Miranda, F.R., R.E. Yoder, J.B. Wilkerson, and L.O. Odhiambo. 2005. An autonomous controller for site-specific management of fixed irrigation systems. Computer and Electronics in Agriculture, 48(3)183-197.

Seyfried, M.S., and M.D. Murdock. 2001. Response of a new soil water sensor to variable soil, water content, and temperature. Soil Sci. Soc. Am. J., 65:28–34.

Seyfried, M.S., and M.D. Murdock. 2004. Measurement of soil water content with a 50-MHz soil dielectric sensor. Soil Sci. Soc. Am. J., 68:394–403.

Sui, R. and J. Baggard. 2015. Wireless sensor network for monitoring soil moisture and weather conditions. *Appl. Eng. in Agric.*, 31(2):193-200. DOI 10.13031/aea.31.10694.

Sui, R., H.C. Pringle, and E.M. Barnes. 2013. Evaluation of soil moisture sensors. In Proc. Irrigation Show and Education Conference. Falls Church, VA. : Irrigation Association.

UCS. 2011. http://www.ucsusa.org/gulf/gcstatemis_cli.html. Accessed in May 28, 2011.

Vellidis, G., M. Tucker, C. Perry, C. Kvien, C. Bednarz. 2008. A real-time wireless smart sensor array for scheduling irrigation. Computer and Electronics in Agriculture, 61:44-50.

Vories, E.D. and S.R. Evett. 2010. Irrigation research needs in the USA Mid-South and Southeast, humid and sub-humid regions. 5th National Decennial Irrigation Conference Proceedings, 5-8 December 2010, Phoenix Convention Center, Phoenix, Arizona USA IRR10-8679.

Yao, T., P.J. Wierenga, A.R. Graham, and S.P. Neuman. 2004. Neutron probe calibration in a vertically stratified vadose zone. Vadose Zone J., 3:1400–1406.

Yoder, R.E., D.L. Johnson, J.B. Wilkerson, D.C. Yoder. 1997. Soil water sensor performance. Applied Engineering in Agriculture, 14(2):121-133.