MONITORING ROOT ZONE SALT AND WATER DYNAMICS UNDER DRIP AND SPRINKLER IRRIGATED COTTON

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Abstract

This study was conducted at three Oklahoma cotton fields under subsurface drip and sprinkler irrigation systems. Different types of soil moisture and salinity sensors were installed in order to monitor salt and water dynamics in cotton root zone during the growing season. The results confirmed that soil sensors provide valuable information that can assists producers in making informed decisions. Water availability in the root zone was strongly related to the amount of applied water (precipitation and/or irrigation) as well as cotton water use (influenced by both crop condition and atmospheric demand). Comparing soil salinity levels between two adjacent fields, one under subsurface drip and another under sprinkler irrigation, revealed that soil salinization under drip irrigation may become a major issue in the future since salts tend to accumulate at the outer edges of the wetting front under this type of irrigation system.

Introduction

Cotton is the dominant irrigated crop in the southwest Oklahoma, accounting for about 60,000 irrigated acres based on the Farm and Ranch Irrigation Surveys conducted in 2003 and 2008 by the USDA National Agricultural Statistics Service. In the past several years, however, this region has experienced prolonged periods of severe to exceptional drought and consequently a significant decline in freshwater resources. For example, water level in the Lake Altus has dropped to 31 ft below the normal pool elevation as of Jan. 13th, 2015 (the Oklahoma Water Resources Board). As a result, no irrigation water has been delivered to over 40,000 acres of farmlands in the Lugert-Altus Irrigation District since 2011. The scarcity of water supplies was the main reason behind a significant decrease in irrigated cotton acres to about 26,000 acres in 2013. The most recent drought monitor map (1/13/2015) shows that the four southwest counties of Harmon, Greer, Jackson, and Tillman are almost entirely under the most intense category of drought: D4 (exceptional drought). The condition does not seem to improve in the near future, as the seasonal drought outlook published by the NOAA Climate Prediction Center indicates that drought will persist or intensify over the western Oklahoma for the period of January 15 to April 30, 2015.

The current and predicted water scarcity in the region necessitates major improvements in irrigation efficiencies and minimization of water losses. Recent technological advances have resulted in irrigation systems that apply water efficiently and allow growers to apply a high level of control on irrigation management. Examples include the ability to monitor and control center pivot movements and operation at or near real-time through web-based user interfaces and smart-phone applications. However, hardware improvements will not translate into actual water conservation and increased water productivity unless they are accompanied by software improvements, i.e. irrigation management. Even the most advanced irrigation systems will result in water loss if water is applied in excess of moisture deficit in the crop root zone. One approach to improve irrigation management is to make irrigation decisions based on data collected by soil moisture sensors installed at multiple depths within the root zone. Some of the main advantages of irrigation scheduling using soil moisture sensors are the level of accuracy that can be achieved, the ease of practical implementation of this approach, the availability of many commercial systems, and the ability to automate irrigation scheduling (Jones, 2004). Vellidis et al. (2008) recently developed a cost-effective wireless soil moisture sensor array that can be used to apply precision irrigation management in fixed and variable-rate irrigation systems.

A field study was conducted in Oklahoma during the 2014 growing season to evaluate the potential of different types of soil moisture sensors to be used for precision irrigation scheduling of cotton. Improvements in irrigation scheduling can lead to water conservation, which will help cotton growers during drought years. A second objective of the project was to investigate the potential for salt accumulation under Subsurface Drip Irrigation (SDI) systems. The need to study the risk of salt accumulation also stems from the recent water scarcity in the region. As freshwater supplies diminish, cotton growers consider converting to more water-conserving irrigation systems such as SDI. They also explore using alternative sources of water, such as shallow groundwater resources with low quality. The combination of low-quality irrigation water, below-normal rainfall (required to leach the salts), and SDI systems which apply small amounts of water to a portion of the field may result in soil salinization to levels beyond cotton salt tolerance. In addition, accumulation of other toxic elements such as boron and selenium may cause significant sustainability issues (Ayars et al., 1993).

Materials and Methods

A demonstration/research project was conducted during 2014 growing season at a cotton field near Hydro, OK and two fields near Martha, OK. Different types of sensors were installed at these fields to study salt and water dynamics in the root zone of cotton. Weather data were obtained from nearby Mesonet stations (McPherson et al., 2007).

Hydro Site

The field at Hydro had a recently-installed center-pivot system (Valley® 8000 series) equipped with a TouchProTM control panel. Three irrigation treatments were selected for this study at full well capacity (100%), 75% of the full treatment (75%), and dryland (0%). The dominant soil type at this site was Pond Creek Loam. Cotton (NG 1511 B2RF) was planted on May 20, 2014 at the seeding rate of 48,000 and row spacing of 36 inches. Six Watermark sensors (Irrometer Company, Inc., CA, USA) were installed at each irrigation treatment at three depths of 10, 24, and 36 inches below the soil surface and two replications. A soil temperature sensor was also installed at each replication to correct for the effect of soil temperature on Watermark readings. In addition, two tipping-bucket rain gauges were installed at 100% and 75% irrigation treatments to measure irrigation and rainfall amounts. The top of the rain collectors were at 40 inches above the ground, providing enough clearance for the center pivot nozzles that were 60 inches above the ground. Data measurement and storage was conducted on an hourly basis and controlled by an Irrometer data logger (model 900M). Figure 1 presents photos of the instrumentation site at the 75% irrigation treatment, taken on three different days during the season.

Figure 1. Instrumentation site at 75% treatment on Jun 12 (left), Aug 5 (center), and Nov 7 (right), 2014.

Martha Site

Two adjacent cotton fields were instrumented at Martha site. The first field was under a center pivot irrigation system, while the second site was under a Subsurface Drip Irrigation (SDI) system. Soil moisture was monitored using Acclima sensors (Acclima, Inc., ID, USA), which take advantage of the Time Domain Transmissivity (TDT) method to measure soil moisture and salinity (electrical conductivity). Eight Acclima sensors were installed at the SDI field at two depths below the soil surface (15 and 30 inches), two distances from the drip tapes (zero and 36 inches), and two replications. The two distances were selected to explore the accumulation of salts in between the drip tapes, installed at 72 inches spacing. Cotton (DP 1219) was planted on Jun. 1, 2014 at the SDI field. Six Acclima sensors were installed at the center pivot field at three depths of 10, 24, and 36 inches below the soil surface and two replications. Cotton (DP 1044) was planted on May 29, 2014 at the center pivot field. Data measurement and storage was controlled using an Acclima data-logger (DataSnap). Irrigation water and soil type were similar for both fields, with Sandy Loam texture for the top 15 inches and Sandy Clay Loam for 15-30 inches zone. Figure 2 demonstrates photos taken at the SDI field at three different dates during the season.

Figure 2. Instrumentation site at the SDI field on Jul 15 (left), Aug 18 (center), and Nov 3 (right), 2014.

Results and Discussion

Hydro Site

During the 146-day study period from mid-June to early November, the rain gauges at the Hydro site recorded 15.6 and 15.9 inches of rainfall at the 100% and 75% irrigation treatments, respectively. These estimates agree well with the 15.6 inches of rainfall measured at the closest Mesonet Station at Hinton, OK. The cumulative irrigation depths over the same period were 6.6 and 4.9 inches at the 100% and 75% irrigation treatments, respectively. The average depths of water applied in each irrigation event were 0.4 and 0.3 inches, considerably less than the depths entered in the control panel by the grower, which were 0.8 inches for the full treatment and 0.6 inches for reduced treatment (75%). Since the system was new and no leaks were observed, the difference between programmed and applied depths is probably due to diminished well capacities. Part of this difference may be also due to direct evaporation of droplets and wind drift losses before irrigation water reached the rain gauges. Figure 3 demonstrates measured irrigation depths plotted against time of the day and day of the year. As the plots suggest, there is a significant variation in irrigation depths, but no daily or seasonal trend could be observed in the data. This was against the expectation that smaller depths should be recorded for irrigation events that occurred during warmer times of the day (due to losses) and toward the end of the season (due to groundwater decline). The reasons behind measuring significantly smaller irrigation depths are still under investigation.

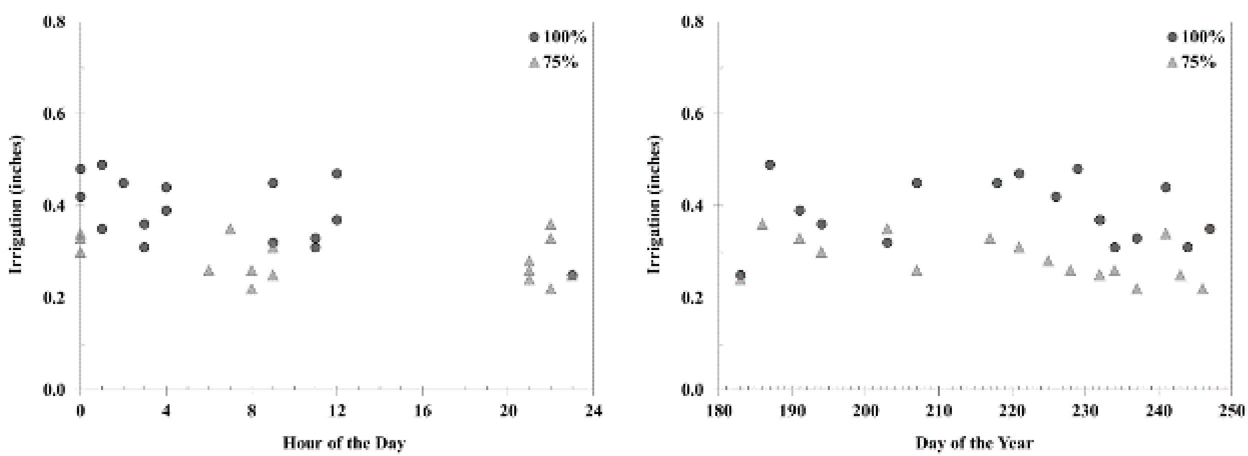

Figure 3. Depths of applied irrigation water measured plotted against hour of the day and day of the year.

Soil moisture data provided valuable information about soil moisture fluxes. Figure 4 presents time series of soil matric potential measured by the Watermark sensors for the three irrigation treatments. Several observations can be made based on the data. For example, the graphs for 100% and 75% irrigation show that the soil profile was almost full until about late July. In particular, the sensors at 36 inches were relatively constant at about 20 centibars, which is close to the Field Capacity (FC) limit. This means that applying irrigation water prior to this date was not very useful in helping the crop going through the upcoming hot and dry periods, since any applied water would be lost to deep percolation. The data also shows when the crop starts to extract water from different depths. As an example, water extraction started in late June, early July, and late July at 10, 24, and 36 inches at the 100% treatment. At this treatment, the slope of soil moisture decline in the beginning of the season was largest for the shallowest sensor and smallest for the deepest sensor, indicating that more roots were present at shallower depths and thus extracting more water. The depletion of soil moisture was larger at the 75% treatments compared to the full treatment and even the 2.5 inches of rainfall that occurred on July 30 was not enough to fully refill the top-soil to the FC level.

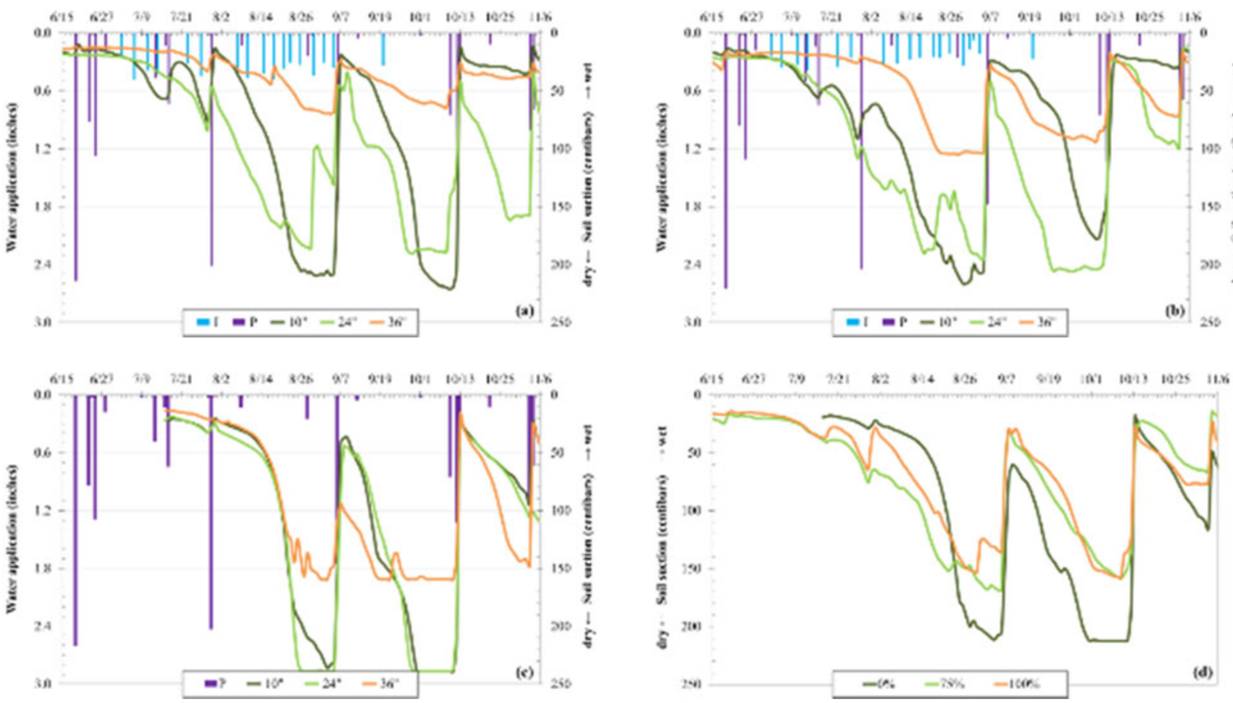

Figure 4. Time series of soil matric potential measured at three depths at treatments 100% (a), 75% (b), and dryland (c), as well as average matric potential for all three treatments (d). When applicable, irrigation and precipitation depths are also presented on a separate ordinate.

When averaged over all three depths (Figure 4d), the dryland treatment had the largest moisture depletion, with average soil matric potential values that reached over 200 centibars. However, this treatment had the smallest moisture depletion for a short period at the beginning of data collection (prior to mid-Aug), most probably because of the poor stand and reduced water extraction capacity of cotton. The difference between 100% and 75% treatments was more significant during the first 2.5 months of study, but the average soil matric potential graphs were very similar after the 1.8 inches of rainfall that occurred on Sep 6, 2014. The total depth of applied water (both irrigation and precipitation) was 23.9, 22.2, and 17.3 inches at 100%, 75%, and dryland treatments for the period between planting (May 20) and Sep 30, 2014. The total cotton evapotranspiration based on the data collected by the Mesonet station at Hinton was 27.9 inches for the same period, suggesting that even the 100% treatment may have been under some level of water stress. This observation is supported by soil matric potential data, as most irrigation scheduling plans suggest irrigating before the matric potential reaches levels measured in the present study.

Martha Site

The Acclima soil moisture sensors provided valuable information about the two irrigated cotton fields near the city of Martha, OK. Figure 5 demonstrates time series of daily averaged soil moisture measurements in volumetric percentage. At the SDI field soil moisture was at higher levels during the first month of data collection and responded to irrigation application, but decreased at all depths and distances in mid-July and remained at the same levels for the rest of the season. This suggests that irrigation could not keep up with increased water use of crop during this period.

According to the precipitation data from the Mesonet station at Altus (the closest weather station), only 2.0 inches of rainfall was recorded during the two months of August and September. The largest average soil moisture during the data collection period belonged to the sensor closest to the tape at the shallowest depth (0”-15”), with a value of 14.1%. The second largest value was recorded at the sensor farthest from the drip tape and 30” depth (36”-30”), with a value of 12.2%. The sensor closest to the tape at 30” depth (0”-30”) was the next with an average soil moisture of 10.4%. The smallest average soil moisture was recorded at the sensor farthest from the tape at shallowest depth (36”-15”) with an average value of 10.0%.

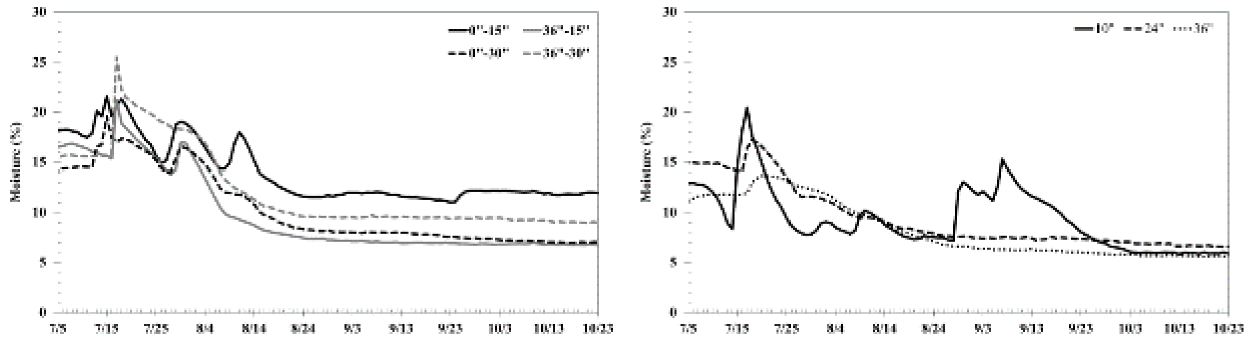

Figure 5. Daily averaged volumetric soil moisture at the SDI (left) and center pivot (right) fields.

The soil moisture data collected at the center pivot field was similar to the SDI field, with the exception that irrigation events in early September were able to increase the water content in the top-soil. However, the applied water did not make it to deeper layers as sensors at 24 and 36 inches did not show any increase in volumetric water content. Water dynamics at this field during the month of July represent a classic example of soil moisture fluctuations, where fluctuations decrease with the measurement depth. Soil moisture data averaged over the study period were 9.4, 9.4, and 8.3% at 10, 24, and 36 inches depths.

Since Acclima measurements are based on TDT principals, soil electrical conductivity (EC) estimates are affected by the soil volumetric water content. Thus, a salinity comparison between the SDI and center pivot fields is only valid if soil moisture data are taken into consideration. Figure 6 presents Acclima EC plotted against corresponding soil moisture for the two fields. Salinity levels were clearly higher at the SDI field for the same values of soil moisture. This finding suggests that salt buildup under SDI may become an issue at the studied field unless enough irrigation and/or precipitation water is applied to leach the salts below the root zone.

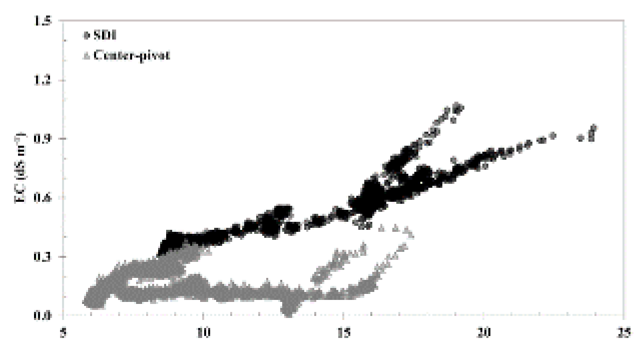

Figure 6. Daily averaged volumetric soil moisture at the SDI (left) and center pivot (right) fields.

Salinization Risk for Southwest Oklahoma

The salinization risk could be serious for southwest Oklahoma under current and predicted water scarcity. This is especially the case if growers decide to use lower-quality water supplies for irrigation purposes. Several previous studies have shown that saline water irrigation could be sustainable, but only if it is used in conjunction with high-quality water through cyclic use or blending (Rhoades et al., 1989). In a furrow-irrigated cotton field in southwest

Spain, Moreno et al. (2001) reported that only one irrigation with saline water (22.7 dS m^{-1}) increased soil salinity of the top soil and impacted cotton growth. It took five irrigations with high quality water (0.9 dS m^{-1}) to bring soil salinity to levels before the saline water irrigation. In northwest China, Chen et al. (2010) concluded that deficit irrigation of cotton with saline water was not sustainable. The average soil salinity in the top 3.3 ft of the soil increased by 336% and 547% after three years of irrigation with saline water of 3.6 and 6.7 dS m^{-1}, compared to the plot that received high-quality irrigation water (0.3 dS m^{-1}). Irrigation water samples from southwest Oklahoma usually exceed these levels, with values reaching 30 dS m^{-1}. Another issue is the presence of toxic elements in irrigation water. Ayars et al. (1993) reported that irrigating with water that has a boron level above 4 mg L^{-1} is not sustainable and can have a considerable negative impact on production of even boron-tolerant crops. Many irrigation water samples from the area have very low boron levels, but some have higher levels reaching 6 mg L^{-1}.

Summary

The results of a research and demonstration project conducted at three irrigated cotton fields revealed that soil moisture sensors can be used effectively to provide detailed information on soil water dynamics. The information collected by commercially-available sensors can assist growers with implementing precision irrigation management strategies. Examples of the information that can be obtained include, but are not limited to: the moisture status of soil profile at different times (e.g. before planting), the effectiveness of rainfall events in refilling the root zone, and the infiltration depth of irrigation water. The soil salinity data collected at two adjacent fields with similar soil types and irrigation water showed that soil salinity was higher at the SDI field compared to the field under center pivot irrigation. This is most probably due to reduced leaching under SDI systems and suggests that soil salinization may become an issue in southwest Oklahoma if SDI systems are used with low-quality irrigation water during drought years when the rainfall does not provide the required leaching.

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