Presented at 2018 Irrigation Show & Education Conference, December 3-7, 2018, Long Beach, California, USA

Comparison of Sensor-Based Irrigation Scheduling Method and Arkansas Irrigation Scheduler

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Abstract: Sensor-based irrigation scheduling methods (SBISM) use sensors to measure soil moisture and schedule irrigation events based on the soil-water status. With rapid development of soil moisture sensors, more producers have become interested in SBISM. Arkansas Irrigation Scheduler (AIS) is a weather-based irrigation scheduling tool and has been adopted in the Mid-South for many years. Field studies were conducted for two years in Mississippi Delta to compare the SBISM with the AIS. Soil moisture sensors were installed in multiple locations of a soybean field. Soil water contents of the field were measured across the growth season. Meanwhile, the AIS was installed in a computer. A weather station near the soybean field was employed to obtain all data required by the AIS. Number and time of the irrigation events triggered by the SBISM were compared with those scheduled by the AIS. Results showed the number and time of irrigation events scheduled using the SBISM were often different from those predicted by the AIS, especially during the 2018 growing season. Both the sensor-based irrigation scheduling method and the AIS could be used as tools for irrigation management in the Mid-South region, but extra attention to the effective portion of rainfall or irrigation would be needed in some years.

INTRODUCTION

Irrigated agriculture in the US is a major consumer of freshwater, accounting for 80% of the nation's consumptive water use (Schaible and Aillery, 2015). Irrigation is essential for crop production in arid and semiarid regions. However, in recent years, acreage of irrigated land has increased rapidly the Mid-South region including the Mississippi Delta (MD). MD is one of the major crop production regions in the United States. Though typical annual precipitation is about 130 cm in this area, only about 18% of the precipitation occurs during June to August when crops require a large quantity of water. Furthermore, the precipitation patterns in summer frequently include heavy rainfall events that increase runoff from cropland with only a small amount of rainfall percolated into the soil profile and available for plant use. Uncertainty in the amount and timing of precipitation is one of the most serious risks to crop production in MD. Timely irrigation has been shown to increase yields of corn (Sui et al., 2015; Vories et al., 1993) and cotton (Sui et al., 2017; Vories et al., 2007). Producers in this region have become increasingly reliant on irrigation to ensure adequate yields and reduce production risks. Approximately 90 percent of irrigated cropland in this region relies on the groundwater supply from the Mississippi River Valley Alluvial Aquifer. Excessive withdrawal of the groundwater has resulted in a decline in aquifer levels across the region. Ongoing depletion and stagnant recharging of the aquifer jeopardize the long-term availability of the aquifer and place irrigated agriculture in the region on an unsustainable path. It is necessary to seek improved irrigation technologies to increase water use efficiency for sustainable use of water resources.

Irrigation scheduling is one of the irrigation technologies to determine the time and amount of water to apply. Irrigation scheduling methods include weather-based, soil moisture-based, and plant-based methods. Weather-based methods schedule irrigation based on the estimated amount of water lost by plant evapotranspiration (ET) and the amount of effective rainfall and irrigation water entering into the plant root zone. Soil-based methods measure soil moisture or water potential levels in the plant root zone and water is applied when there is a water shortage for plants. Plant-based methods directly detect plant responses to water stress and irrigation is initialized as plants indicate suffering from water stress.

In soil moisture-based irrigation scheduling, 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. Electromagnetic (EM) sensors, such as electrical capacitance and resistance type sensors, and time-domain reflectometer (TDR) devices have been rapidly developed and widely adopted for soil moisture measurement in irrigation scheduling (Dukes and Scholberg, 2004; Evett and Parkin, 2005; Fares and Alva, 2000; Miranda et al., 2005; Seyfried and Murdock, 2001; O'Shaughnessy and Sui, 2018; Sui, 2018; Sui and Baggard, 2015; Vellidis et al., 2008).

The Arkansas Irrigation Scheduler (AIS) was developed in the 1970s and early 1980s under the leadership of Dr. James Ferguson to aid Arkansas farmers in managing irrigation. It has been in use for almost forty years in Arkansas and surrounding states. The AIS uses a water-balance approach to scheduling irrigation. The system balance represents the soil water deficit (SWD), the difference between the soil's existing moisture content, summed over the rooting depth, and the moisture content of the soil at its well-drained upper limit. Deposits to the system include rainfall and irrigation. Withdrawals from the system include crop evapotranspiration (ET_c), runoff, and deep percolation below the root zone. Deep percolation is considered negligible when the SWD > 0 and is therefore not considered in the program. Rooting depth is not used explicitly in the program, but is implicit in the choice of a maximum allowable SWD (Vories et al., 2009).

The objective of this study was to compare the sensor-based irrigation scheduling method (SBISM) with the Arkansas Irrigation Scheduler (AIS) in irrigation scheduling.

MATERIAL AND METHODS

The study was conducted in 2017 and 2018 in a 6.7-ha field at the USDA ARS Research Farm in Stoneville, Mississippi, USA (latitude: 33°26'30.86", longitude: -90°53'26.60"). Silt loam was the predominant soil type in the field. The field was a quadrant of the area under a center pivot irrigation system. Three irrigation treatments were set up in the field, which are variable rate irrigation (VRI), uniform rate irrigation (URI), and rainfed. VRI and URI treatments were assigned in the area under the pivot while the area in the corner of the field was assigned for rainfed treatment. Irrigation scheduling in both VRI and URI treatments was performed using the SBISM. Soybean was planted in the field on April 7 in 2017 (cultivar: HBK4950) and April 20 in 2018 (cultivar: HBK4855). The studies were harvested on September 9 in 2017 and October 4 in 2018. Insects and weeds in the field were controlled with generally recommended procedures in the region throughout the growing seasons.

For irrigation scheduling, GS-1 soil water content sensors (Decagon Devices, Pullman, Washington, USA) were employed to measure soil volumetric water content (VWC) in four locations within the field. In each location, three sensors were installed at three depths (15, 30, 61cm).

To install the sensors, a hole was drilled at the center of the crop row using a soil auger. The sensors were inserted horizontally into the soil at the designated depths. One data logger (EM50R/G, Decagon Devices, Pullman, Washington, USA) was used to collect soil moisture data from the sensors. Data loggers were set up to continuously make one measurement of soil water content every minute and calculate the hourly average of the measurements. Readings of the soil water content from the logger were downloaded wirelessly.

Soil water content measured using the sensors was used for irrigation scheduling. Soil water content measurements at the three depths were interpreted using a weighted average method to reflect the importance of soil water in different depths across the plant root zone. A weight was assigned to each sensor measurement based on the sensor depth as 0.45, 0.35, and 0.2 for the sensor depth of 15, 30, 61cm, respectively. The weighted average of the VWC was used for irrigation scheduling. In this region, it is very common that long-lasting rainfalls occur in early crop growing season to saturate the soil. Soil VWC measured by the sensors in field at 48 hours after soil was saturated was used as the sensor-measured field capacity (FC). VWC at permanent wilting point (PWP) of the soil was determined based on the soil type (Sandall, 2018). Irrigation was triggered when the plant available water (PAW) dropped close to 50%.

PAW is defined as follows:

$$PAW = \frac{(Sensor\_measured\ VWC) - (VWC\ at\ PWP)}{FC - (VWC\ at\ wilt\ point)}$$

In general, at each irrigation event, a 19mm depth of water was applied to the 100% rate zone of VRI treatment and all zones of URI treatment. Water depth applied to the other zones of VRI treatment was scaled down according to the rate assigned. Irrigation water was delivered using a center pivot VRI system.

A weather station located near the soybean field was used to collect weather data including daily ET_o. Irrigation events were triggered by the soil water content measured by the sensors. The amount of irrigation water applied in each scheduled irrigation event was recorded.

A stand-alone version of the Arkansas Irrigation Scheduler (AIS, version 2.3.4) was installed in a computer. According to the operation instructions of the AIS, the data were entered in the AIS program, including planting date, initial soil moisture status, daily ET_o, amounts of rainfall and irrigation. The AIS calculated the daily water deficit with these input data. It was assumed that any rainfall was effective (i.e., entered the soil) until the SWD was replaced and any additional amount ran off the field.

RESULTS AND DISCUSSION

The total precipitation and ET_o were 656mm and 433mm, respectively in the 2017 growing season. The soil water content change across the growing season in 2017 was illustrated in Figure 1. Soil moisture sensors responded well to major precipitations, especially the sensor in the 15cm depth. The sensor-measured soil moisture was used to trigger the irrigation events. Based on the weighted soil VWC, the first irrigation in the amount of 19mm was scheduled on July 21 as the weighted soil VWC dropped to 31%. Another three irrigations were conducted on July 27 in amount of 19mm, August 1 in amount of 22mm, and August 4 in amount of 19mm (Fig. 2) to maintain a low water deficit considering the crops were in the R3-R4 stages, in which the plant is more susceptible to water stress than the other growth stages. Though the weighted soil VWC dropped below the irrigation trigger level around May 20th and June 15th, irrigation was not scheduled for two reasons: the plants were at stages in which they are more tolerant to water stress, and the weather forecast indicated a precipitation event coming soon.

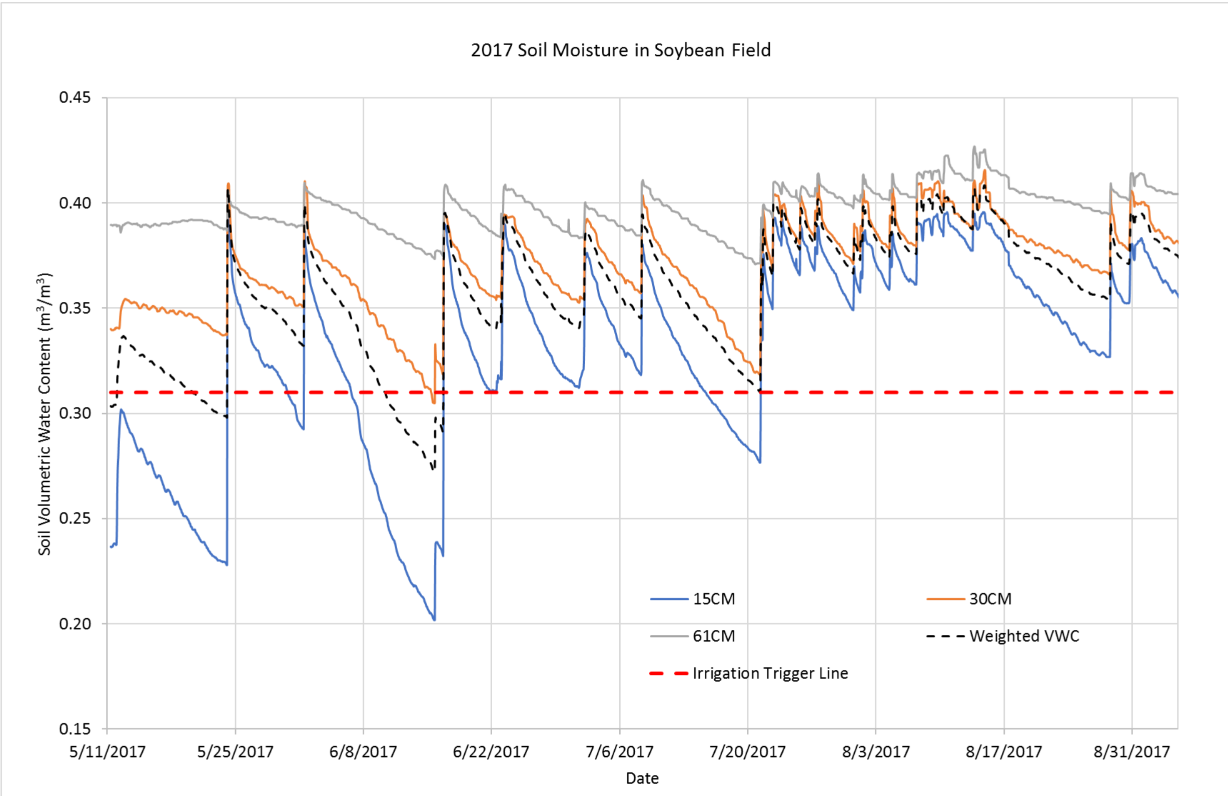

Fig. 1. Soil water content measurements across the 2017 season in soybean field. Irrigation trigger level was set at 31% weighted average soil volumetric content.

The daily inputs to the AIS (amount of ET_o, precipitation, irrigation) and the SWD predicted by the AIS in the 2017 growing season are shown in Figure 2. An allowable SWD of 37 mm was selected to call for an irrigation event, although all irrigations were scheduled by the SBISM. The deficit estimated by the AIS on July 20th was 43mm, which indicated an irrigation was needed (Fig. 2). This prediction matched fairly well with the measurement results of the soil moisture sensors (Fig. 1), although the AIS date would have been 3 days earlier. On June 14th, when the sensor-measured soil moisture suggested to schedule an irrigation (Fig. 1), the AIS deficit prediction was 31mm, which was slightly below the irrigation trigger level of 37mm (Fig. 2). The AIS also indicated a predicted deficit of 32mm on August 27, near the 37mm trigger. However, the sensor-based scheduling method did not suggest the irrigation at that time (Fig. 1). This could be caused by deficit over-prediction by the AIS at the late growth stage of the soybean plants. It was also observed that the sensor-measured soil moisture dropped below the irrigation trigger line on May 20th, but the AIS predicted deficit at that time was 14mm which is considerably lower than the irrigation trigger level of 37mm (Fig. 1). It should be noted that the AIS adjusts the crop coefficient curve based on soybean maturity group (MG); however, actual soybean cultivars tend to vary more than the adjustments can account for. While the cultivar HBK4855 is a MG 4, as a late MG 4 it might fit the MG 5 curve more closely.

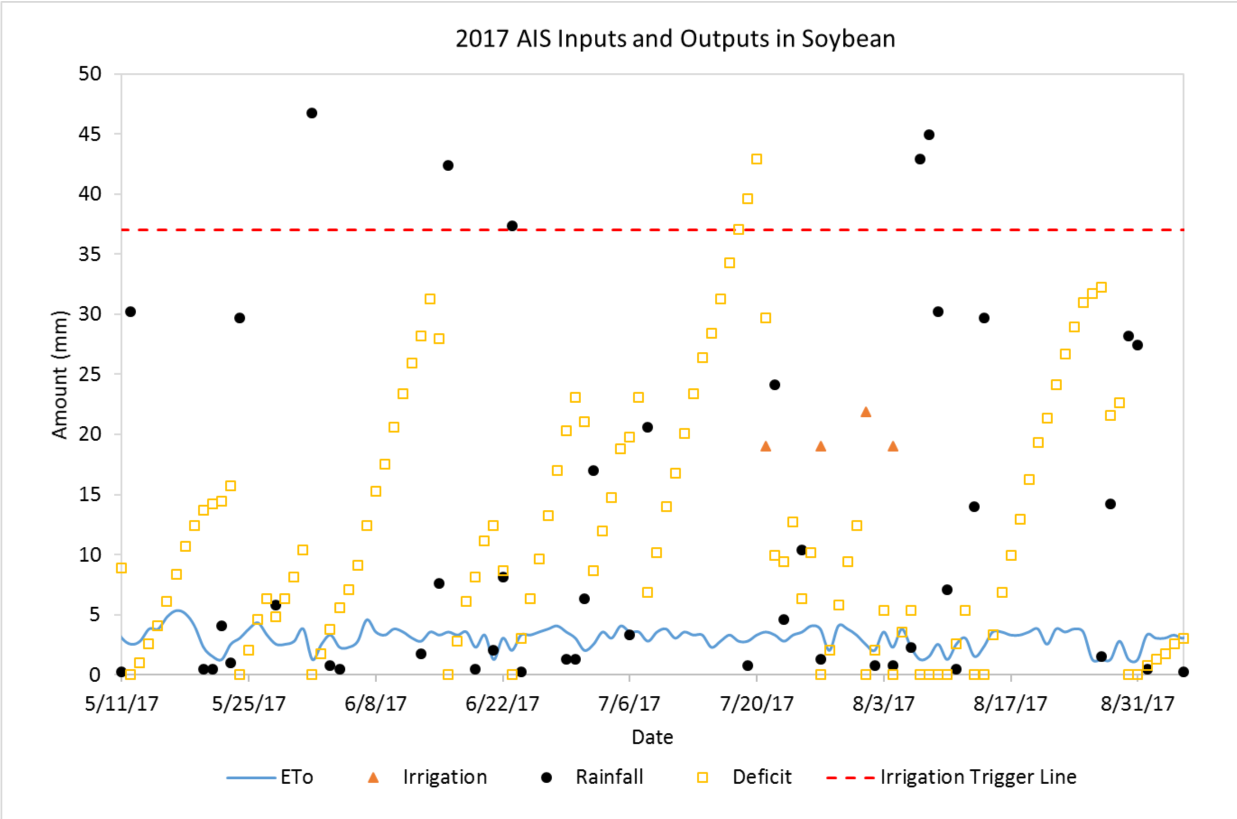

Fig. 2. Inputs to the AIS including ET_o, rainfall, irrigation, and the AIS output of estimated deficit in 2017 soybean growing season. Irrigation trigger level was set at the AIS predicted deficit of 37mm.

The total precipitation and ET_o were 644mm and 438mm, respectively, in 2018. Starting from June 9th, seven irrigations were scheduled based on the soil moisture measured by the sensors in 2018 (Fig. 3). 19mm water was applied in each irrigation event. The 1st irrigation on June 9th and the 2nd on June 12th did not bring the soil moisture content back up to the irrigation trigger level. The rain on June 13th and 19th increased the soil moisture and charged the soil VWC above the irrigation trigger level. The apparent fluctuation of the VWC at 61cm depth on June 4th was caused by the failure of a sensor at that depth in one location. On July 3rd and July 6th, the third and fourth irrigations were triggered as the soil moisture decreased to 31%. The other three irrigation events on July 26, July 27, and August 15 were scheduled based on the sensor-measured soil moisture. Irrigations should have been conducted between July 28 and August 15 according to the sensor-based irrigation scheduling (Fig. 3). However, due to a problem with the center pivot, no irrigation could be made during that period. The apparent lack of response to irrigation observed in the soil moisture sensors suggests that soil compaction and/or crusting prevented much of the applied water from entering the soil. Unfortunately, such a situation is fairly common in the region.

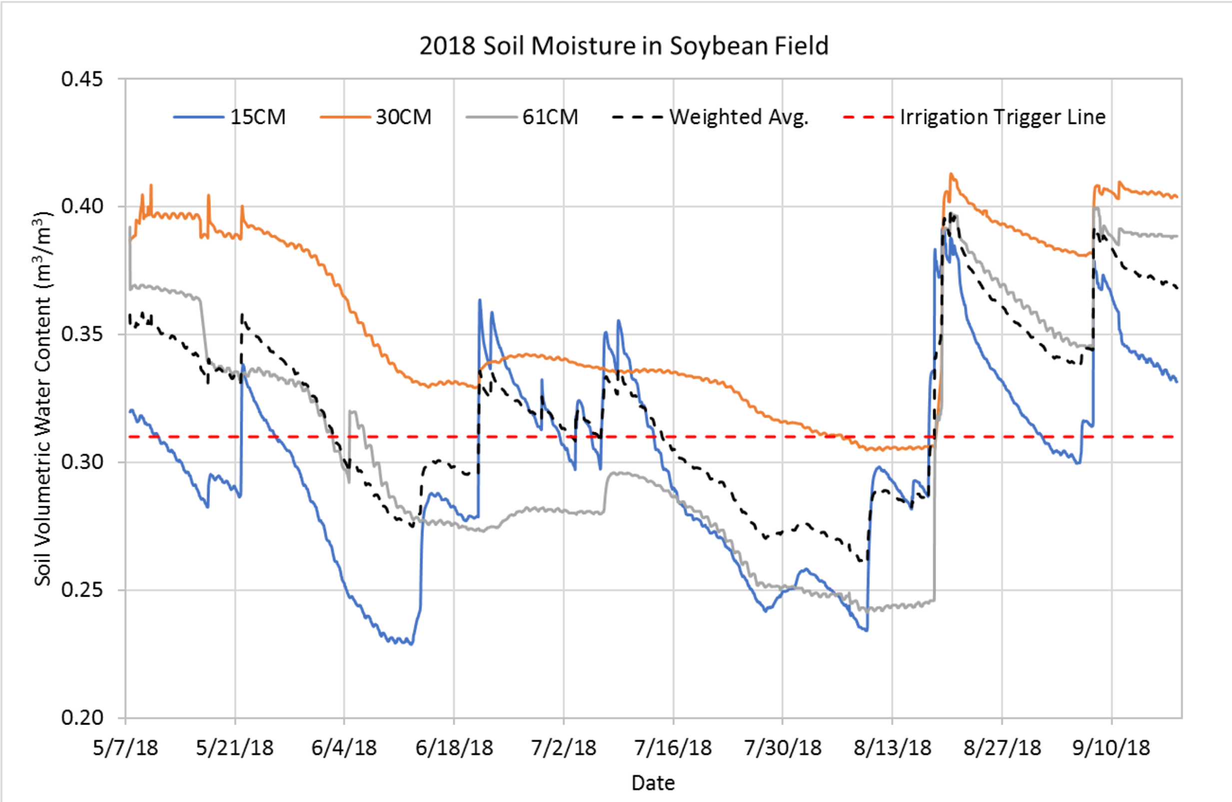

Fig. 3. Soil water content measurements across 2018 season in soybean field. Irrigation trigger level was set at 31% weighted average soil volumetric content.

When the first four irrigations in the 2018 season were scheduled on June 9th, June 12th, July 3rd, and July 6th, the deficits predicted by the AIS were 14mm, 3mm, 27mm, and 22 mm, respectively, which were less than the AIS irrigation trigger level of 37mm (Fig. 4). When the fifth sensor-based irrigation was scheduled on July 26th, the deficit predicted by the AIS was 44mm, which surpassed the AIS irrigation trigger level of 37mm; however, it was 30mm when the sixth irrigation was scheduled on July 27th. When the seventh irrigation was scheduled on August 15th, the estimated deficit was 26mm, which was below the irrigation trigger level. The AIS assumed that all surface water had run off the field within 24h and started accumulating the deficit from zero in the next day, while in reality, such a large rain period often has a longer-lasting effect. The discrepancies between the two methods earlier in the season probably resulted from reduced soil intake suggested by the sensors, while the AIS estimates assumed that the water reached the root zone. This points out a serious shortcoming with water-balance methods like the AIS, knowing how much of a rainfall or irrigation was actually effective and should be used to adjust the deficit.

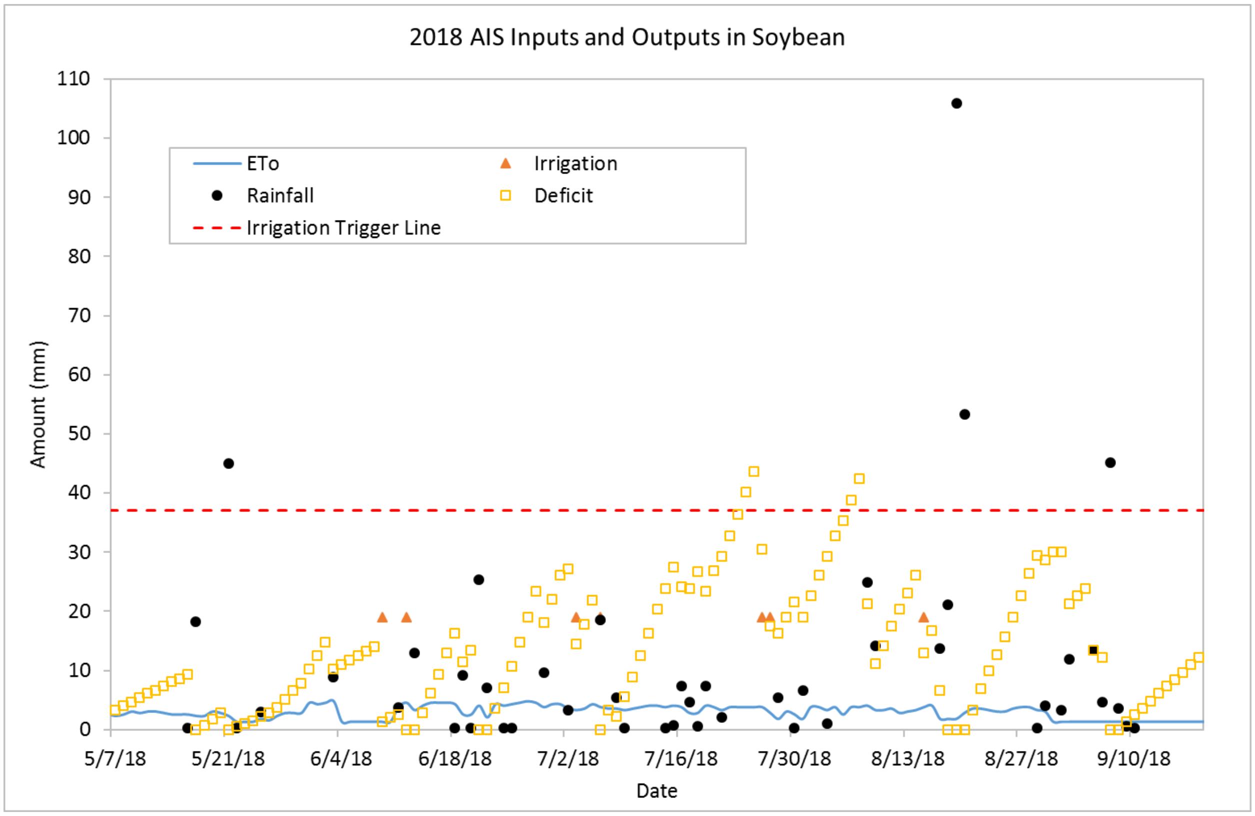

Fig. 4. Inputs to the AIS including ETo, rainfall, irrigation, and the AIS output of deficit output in 2018 soybean growing season. Irrigation trigger level was set at the AIS predicted deficit of 37mm.

CONCLUSION

Field studies were conducted to compare the sensor-based irrigation scheduling method (SBISM) with the AIS (Arkansas Irrigation Scheduler). Two years of tests in soybean crops showed the number and time of irrigation events scheduled by the SBISM differed from those predicted by the AIS, especially in 2018. A couple of mismatching of the irrigation recommendations between these two approaches occurred at the early and late growth season, which might have been caused by the lack of precision in the AIS crop coefficient functions and very high soil moisture content due to large amounts of precipitation in the late growing season. The most pronounced differences were observed in 2018, when the sensors indicated problems with applied water reaching the root zone while the AIS assumed that it did. Both of the SBISM and the AIS could be used as tools for irrigation management in the Mid-South region, but extra care is needed when soil crusting or compaction reduce the effectiveness of irrigation. The wireless soil moisture sensors, which can provide real-time in-situ soil moisture measurement, made the SBISM easy to use. The AIS requires daily weather data from a weather station near the field, which makes it less user friendly. The prediction accuracy of the AIS might be significantly influenced if this requirement could not be met.

Disclaimer

The mention of trade names of commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

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