Seasonal irrigation requirements and irrigation scheduling of soybeans

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Abstract.

While rainfall in Mississippi is usually abundant, the temporal distribution and amount are unpredictable. Soybean producers in Mississippi are increasingly incorporating irrigation practices into their production systems, and are interested in developing tools and strategies to assist in making irrigation decisions and maintaining optimal plant-growth conditions.

A three-year study was begun to evaluate water-use requirements of soybean, evaluate irrigation scheduling methods, and examine impacts of irrigation management on soybean yield and quality. The study was conducted in a 15-ac field under a center-pivot, overhead-sprinkler irrigation system equipped with variable-rate application control capability. Irrigation treatments consisted of varying depths of irrigation water applied, based on evaporative demand (or evapotranspiration, ET), ranging from 0 to 125% of ET.

Two versions of the Arkansas Irrigation Scheduler, and a spreadsheet scheduling model, were tested to determine the timing of irrigations, and four irrigation applications were made during the season. Soil-moisture sensors installed in each plot indicated that soil-water reserves were sufficient throughout the growing season and that the soybean plants under all irrigation treatments may have been exposed to minimal water stress. Average treatment yields ranged from a minimum of 66.9 bu/ac for the non-irrigated treatments to a maximum of 77.8 bu/ac for the 100% ET treatment. An analysis of variance test showed no significant differences ($P = 0.256$) between treatments, indicating that the amount of irrigation water applied did not significantly affect yield. This was most likely a result of the rainfall patterns observed, in which sufficient rainfall occurred at timely intervals.

Keywords. soybean, center pivot, variable rate, soil moisture, irrigation scheduling

Introduction

Rainfall in Mississippi is abundant, but for Mississippi soybean producers, rainfall occurring during the crop-production season is of prime importance. Because the temporal distribution of rainfall is unpredictable and may not be sufficient or timely for satisfying crop-water demands and enabling optimal growth and yield production, producers are increasingly incorporating irrigation practices into their production systems. Irrigation involves the proper timing and amount of water application to satisfy crop-water needs. Proper timing is necessary to avoid drought, or water-stress, conditions, and to avoid overly wet or prolonged periods of waterlogged conditions, both of which can negatively impact plant health and yield. Proper amount of water application is necessary to adequately replenish soil-water resources so that plants have adequate access for continued growth, while minimizing losses through runoff or deep percolation.

In order to enable efficient irrigations and make best use of water resources, the water-use requirements of soybean need to be determined. Water-use is a function of environmental demand, and soybean-plant systems use water through the combined processes of transpiration and evaporation in response to the climatic conditions in which they grow. Since environmental conditions are site-specific, monitoring of climatic conditions and soybean growth, water-use, and yield under local conditions is necessary to provide this information to Mississippi producers.

While irrigation is an important component of a producer's farm management activities, its importance in optimizing plant growth, yield, and quality can be overlooked or neglected. Irrigation can be a labor-intensive and time-consuming activity, and producers often try to simplify the process to better fit in with other farm operations, rather than performing the irrigation when and how it is most effective. Producers are interested in developing tools and strategies to assist in making irrigation decisions and maintaining optimal plant-growth conditions. Since water plays a major role in plant growth processes, metabolic reactions, fruit formation and retention, and disease infection, its proper application can have a significant effect on crop yield and quality.

Objectives

The objectives of this study were to (1) evaluate irrigation scheduling methods, (2) evaluate water-use requirements, (3) monitor soil-moisture status to detect moisture stress, and (4) examine impacts of irrigation management on soybean yield.

Materials and Methods

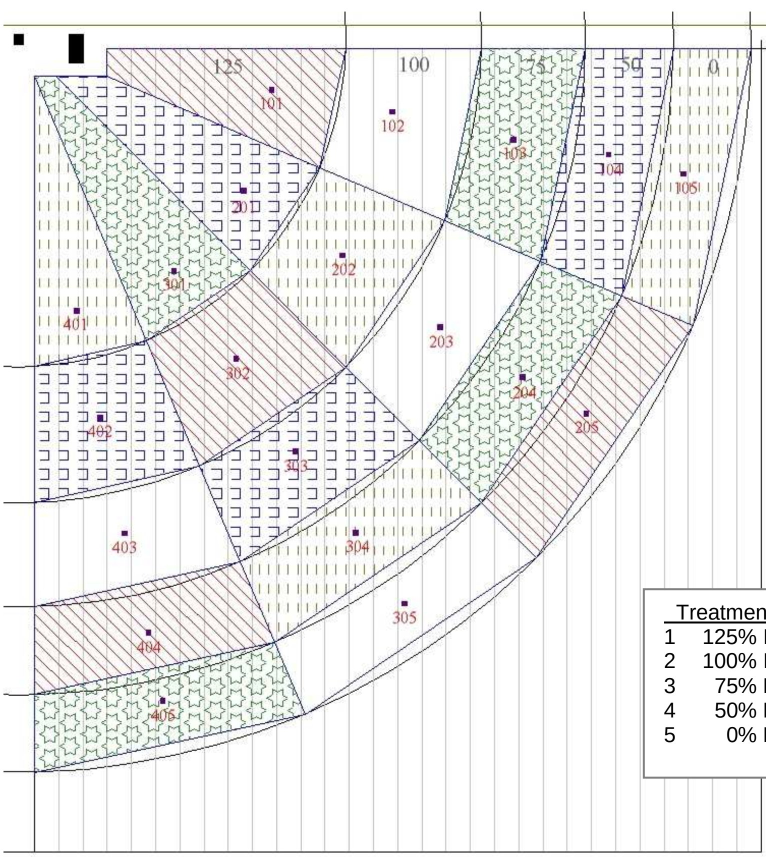
The study was conducted in 2012 at the USDA ARS's Jamie Whitten Delta States Research Center at Stoneville, MS (latitude 33.48 N, longitude 90.98 W, elevation 138 ft). A 15-ac field under a center-pivot, overhead-sprinkler system was planted on 24 April 2012 to soybean, Pioneer P94Y70, with a 38-in row spacing at a density of 120000 seed/ac.

Plots were established under a one-quarter section of the center pivot's circle in a completely randomized block design. Five irrigation treatments were defined, with four replications of each treatment, resulting in a total of 20 plots. Treatments consisted of five irrigation-application levels; 0% (non-irrigated), 50%, 75%, 100%, and 125% of ET (evapotranspiration). The area outside the center pivot's circle was not irrigated. Plot layouts and treatments are shown in Figure 1.

The irrigation system consisted of a Valley model 8000 center-pivot equipped with Valley's Variable Rate Irrigation (VRI) Zone Control (Valmont Irrigation, Valley, NE). The center-pivot system included four spans, with a total length of 766 ft, and 86 sprinklers. The VRI system enabled sprinkler output to be controlled via electric solenoid valves. The sprinklers were each equipped with an electric solenoid valve, and were grouped into 10 zones. Each zone was designed to cover the same surface area as the pivot travelled around the center, with the number of sprinklers in each zone varying from 5 to 27. Each zone could be programmed to operate the solenoid valves with duty cycles varying from 0% (continuously closed) to 100% (continuously open) in 10% increments to vary the amount of water applied. As the pivot travelled around the field, zone settings could be independently controlled every 2 degrees.

Irrigation timing was determined based on evaporative demand (or evapotranspiration, ET) and a water-balance irrigation scheduling method. Daily reference ET (ET_o) was first estimated using the standardized weather-based FAO-56 evapotranspiration method (Allen et al., 1998). Weather data were obtained from an automated weather station at Mississippi State University's Delta Research and Extension Center experiment station at Stoneville, MS. Daily ET_o was calculated using the weather data, then adjusted using a crop coefficient to estimated daily crop ET (ET_c) for soybean. ET_c, rainfall, and irrigation application amounts were then input to an irrigation scheduling program which tracked daily water use and the soil-water deficit. When the deficit reached a preset threshold, an irrigation was scheduled for the following day.

Soil-moisture sensors were installed in each plot to monitor soil-water resources and soil-water extraction, and to monitor the level of water stress. Water-potential sensors (Watermark Model



	Treatment	VRI setting	Plots
1	125% ET	100%	101, 205, 302, 404
2	100% ET	80%	102, 203, 305, 403
3	75% ET	60%	103, 204, 301, 405
4	50% ET	40%	104, 201, 303, 402
5	0% ET	0%	105, 202, 304, 401

Figure 1. Plot layout showing irrigation application treatments.

200SS, Irrometer Company, Riverside, CA) were installed at 6, 12, and 24 in below the soil surface. Sensor measurements were collected with an inexpensive open-source datalogging device (Fisher and Gould, 2012) at 1-hr intervals and stored to a memory card. During periodic site visits, data were downloaded to a tablet computer for later analysis.

During soil-moisture sensor installation, GPS coordinates of each sensor location were recorded, and a "virtual plot" was constructed around the sensor location. The virtual plot consisted of a box 16 rows wide and 50 ft in length centered about the sensor location. The GPS coordinates of the four corners of the box were recorded, and would be used following harvest for yield estimation.

At the end of the season, the field was harvested with a mechanized grain harvester. Yield data was collected and recorded with a GPS-based yield monitor, which measured yield continuously as the harvester travelled across the field. The yield monitor was calibrated by weighing several harvester-loads of soybean in a loadcell-equipped grain cart and entering actual weights into the yield monitor.

Results

The 2012 growing season was warm with dry periods in the Mississippi Delta region. While there were some hot periods during the growing season, monthly average maximum air temperatures were near long-term normal values for June, July, and August. Rainfall during the growing season totaled 17.9 in, approximately 2 in higher than normal, but the majority of the rainfall occurred during three storm events in late May-early June, late June, and late August. Between rain events, little to no rainfall occurred for periods of three to four weeks.

Daily reference ET values ranged between 0.10 and 0.27 in/day during the season, with a seasonal average of 0.19 in/day. Based on a crop coefficient function for soybean with values of 0.2 early in the season, 1.00 during the peak season, and 0.5 at harvest, crop ET ranged between 0.02 and 0.25 in/day. ET_o estimates, maximum air temperature, and rainfall measurements are shown in Figure 2.

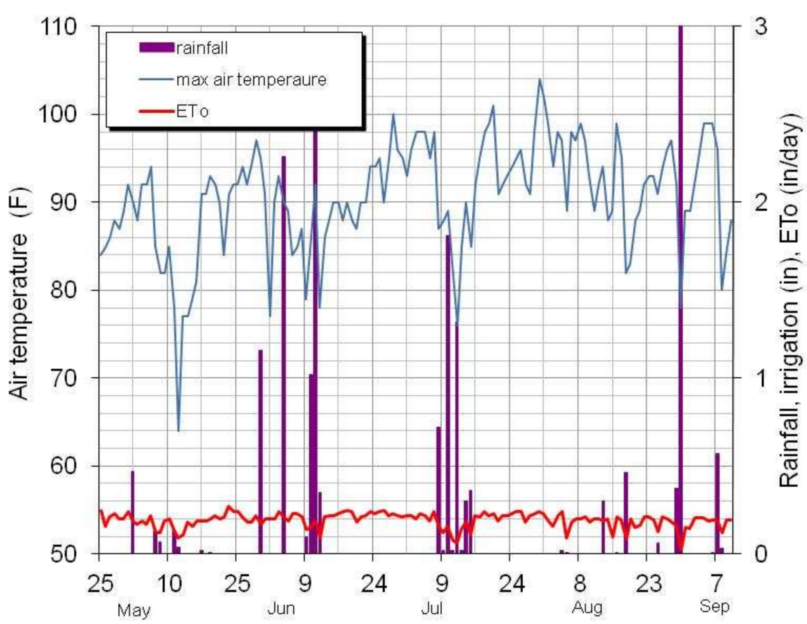


Figure 2. Daily reference ET, air temperature, and rainfall.

Irrigation scheduling

Two water-balance irrigation scheduling models were tested to examine differences in scheduling recommendations. One model, the Arkansas Irrigation Scheduler (Cahoon et al., 1990; Vories et al., 2005), was a stand-alone computer program that required minimal data input to set up (type of crop, irrigation system, planting and emergence dates) and use (daily maximum air temperature or reference ET, rainfall, and irrigation). The Arkansas Irrigation Scheduler, when first written, used air temperature and an empirical correlation to estimate ET_o. The program was later updated to allow the user to directly enter ET_o values, calculated using a reference-ET method such as the FAO-56 Penman-Monteith method, to potentially provide more accurate crop ET estimates and improve the performance of the water-balance model. The program used a built-in crop coefficient function to adjust ET_o and estimate ET_c of soybean.

The second model consisted of a simplified water-balance constructed in a computer spreadsheet (Fisher and Pringle, 2010). ET_o was estimated by an empirical equation developed by Turc (1961), which used maximum air temperature and solar radiation, which was then adjusted with a crop coefficient function to estimate ET_c. A daily soil-water deficit was then calculated by subtracting ET_c and adding rainfall and irrigation amounts to the previous day's deficit.

In making irrigation scheduling decisions during the season, the Arkansas Irrigation Scheduler with FAO-56 ET_o input was used. A deficit of 2.00 in was selected as the threshold for irrigation initiation. When the model's soil-water deficit reached this amount, an irrigation was scheduled for the following day.

Resulting soil-water deficit estimates for the Arkansas Irrigation Scheduler and the spreadsheet model are shown in Figure 3 for the 100% ET treatment. For the Arkansas Irrigation Scheduler, the soil-water deficit increased at a much faster rate when maximum air temperature was used (Figure 3b). This indicates that daily ET_o values generated by the program were higher than those estimated using the FAO-56 method (Figure 3a). Using the temperature-based version, an extra irrigation would have been signaled in late May, and the irrigation on June 29th would have been triggered several days earlier. The rainfall in early July would have been insufficient to replenish soil-water reserves, with an irrigation called for soon after that rainfall event, and excessive soil-water deficit occurring in the latter part of the season. The spreadsheet model (Figure 3c) agreed well with the Arkansas Irrigation Scheduler with ET_o input. Using a spreadsheet had an advantage of providing a graphical output, rather than the simple text output generated by the Arkansas Irrigation Scheduler, allowing for easier interpretation and observance of trends in the soil-water deficit information.

During the season, a total of four irrigation applications were made. The variable-rate center-pivot irrigation system was programmed to apply five application-rate treatments, shown in Figure 1. Based on the design capacity of the center pivot, the 100% treatment was programmed to apply 1.00 in of water during an irrigation, with the other treatments applying an amount proportional to their treatment percentages (125% = 1.25 in, 75% = 0.75 in, 50% = 0.50 in, and 0% = 0 in, or not irrigated). During each irrigation, as the variable-rate system traveled across the field, solenoid valves cycled open and closed to allow the proper amount of water to be applied to each plot.

Soil moisture measurements

Soil-moisture measurements were collected at three depths (6, 12, and 24 in below the soil surface) at the center of each plot at 1-hr intervals throughout the season. Measurements from the four replicates of each treatment were averaged for each depth, and are shown in Figure 4. For each

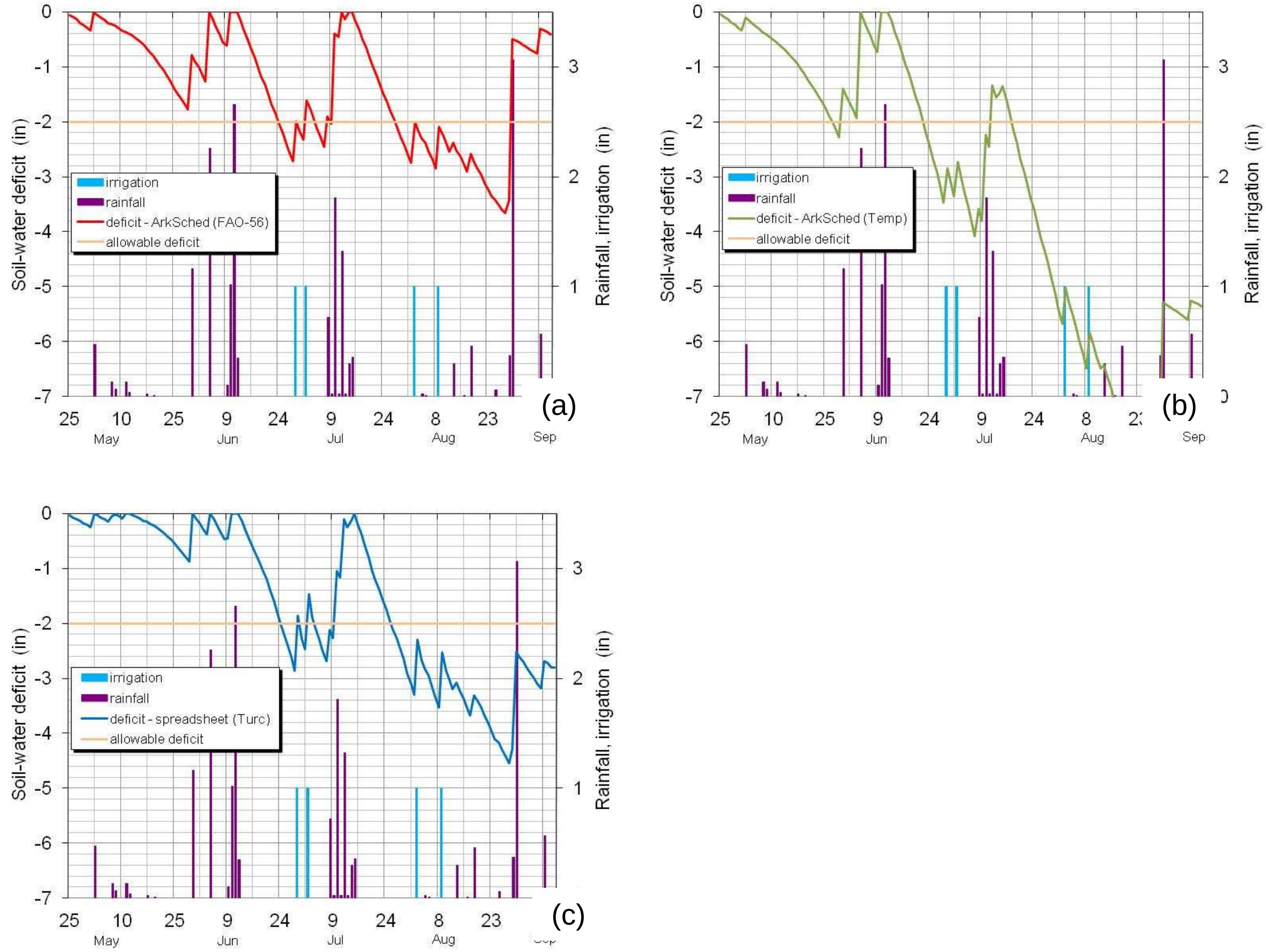


Figure 3. Irrigation schedules from the (a) Arkansas Irrigation Scheduler with ET_o input, (b) Arkansas Irrigation Scheduler with temperature input, and (c) spreadsheet model.

treatment, soil-water potentials remained above the threshold level of -60 kPa for much of the season, suggesting that the plants were not exposed to significant water stress.

The infrequent but heavy rainfall events provided moisture which satisfied crop-water demands for several weeks, minimizing the need for supplemental irrigation. The timing of the first irrigation, signaled by the irrigation scheduling model in late June, agrees fairly well with the soil-moisture sensor data for the 100% ET treatment (Figure 4b). In order to apply 2 in of water, the center pivot was run over the field in one direction, then a few days later in the reverse direction. In early August, the scheduling model called for an additional irrigation, but moisture-sensor data suggest that the plants still had access to sufficient soil-water reserves, and that the irrigation could have waited. The less-irrigated treatments also appeared to be under little stress, and the last two irrigations may not have been necessary.

Yield

On 10 September 2012, the field was harvested, and a yield map was generated from data collected with the GPS-equipped yield monitor, shown in Figure 5. The yield map shows the location of the

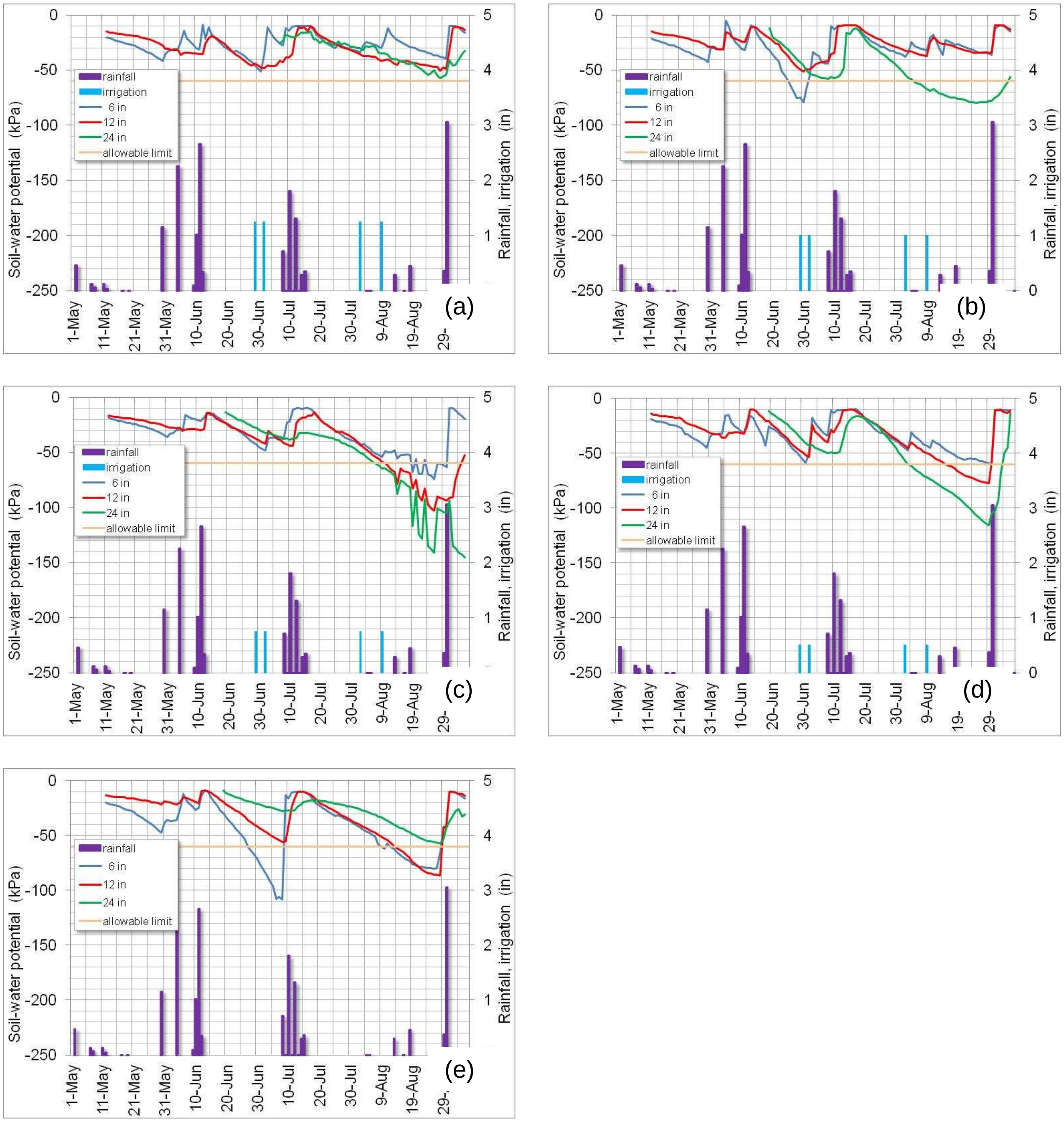


Figure 4. Soil-moisture sensor measurements under each irrigation application treatment: (a) 125%, (b) 100%, (c) 75%, (d) 50%, and (e) 0% (non-irrigated).

pivot's center in the upper-left corner, and the circular sweep of the 5 variable application-rate zones under the center pivot. Extending radially from the pivot's center, three alleyways can be seen, which were made by mowing the soybean plants to allow easier movement within the field during the season and enable visits to each sensor location. Yields generally ranged from around 50-60 bu/ac in the non-irrigated sections to above 90 bu/ac in irrigated areas, with a whole-field average of 67 bu/ac.

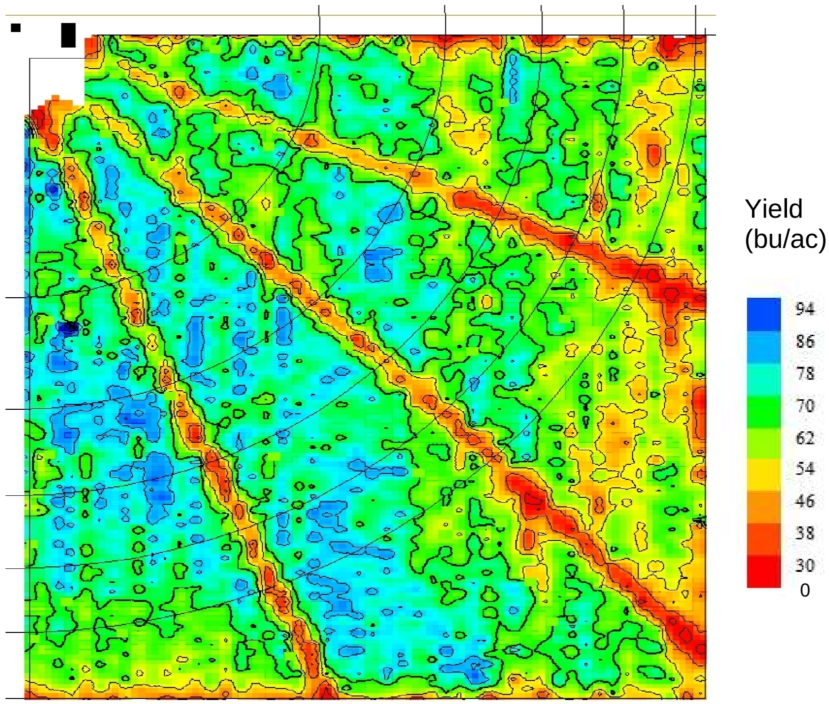


Figure 5. Yield map.

Average yields for each plot were estimated from the virtual plots centered at the moisture-sensor locations within each treatment plot. GPS coordinates of each yield-data point were used to identify those points which were inside the virtual plots. The yield-data points within each virtual plot were then averaged to obtain a yield estimate for each irrigation treatment and replicate. Yields for each plot, and average treatment yields are shown in Figure 6. Average treatment yields ranged from a

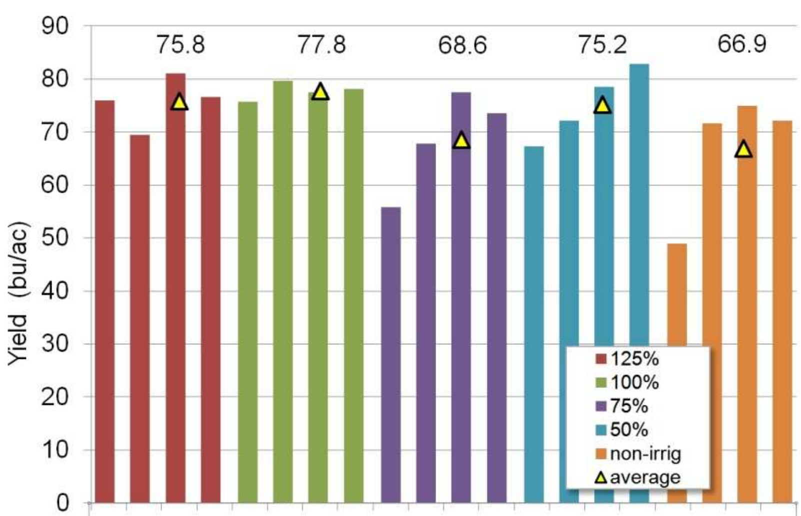


Figure 6. Individual plot and average treatment yields.

minimum of 66.9 bu/ac for the non-irrigated treatments to a maximum of 77.8 bu/ac for the 100% ET treatment.

An analysis of variance test showed no significant differences (P = 0.256) between treatments, indicating that the amount of irrigation water applied did not significantly affect yield. This was most likely a result of the rainfall patterns observed, in which sufficient rainfall occurred at timely intervals, and supplemental irrigation may not have been needed. This is evidenced by soil-moisture sensor measurements which suggest that there was little moisture stress observed in the non-irrigated plots.

Conclusion

Soybean producers in Mississippi are increasingly incorporating irrigation practices into their production systems, and are interested in developing tools and strategies to assist in making irrigation decisions and maintaining optimal plant-growth conditions. A three-year study was begun to evaluate water-use requirements of soybean, evaluate irrigation scheduling methods, and examine impacts of irrigation management on soybean yield and quality.

Two versions of the Arkansas Irrigation Scheduler, one using air temperature to estimate ET_o and the other using FAO-56 ET_o directly as input, were tested. The temperature-based version appeared to greatly overestimate crop ET, and recommend irrigations earlier than needed. A simplified spreadsheet water-balance model was also tested, and agreed well with the ET_o-input Arkansas Irrigation Scheduler predictions.

Irrigation treatments were applied four times in response to the Arkansas Irrigation Scheduler output. The variable-rate irrigation system applied water to the randomly distributed treatment plots in amounts ranging from 0 to 125% of ET.

Soil-moisture sensors installed in each plot indicated that soil-water reserves were sufficient throughout the growing season and that the soybean plants under all irrigation treatments may have been exposed to minimal water stress.

A yield map of the field was generated and used to estimate plot and treatment yields. Average treatment yields ranged from a minimum of 66.9 bu/ac for the non-irrigated treatments to a maximum of 77.8 bu/ac for the 100% ET treatment. An analysis of variance test showed no significant differences (P = 0.256) between treatments, indicating that the amount of irrigation water applied did not significantly affect yield. This was most likely a result of the rainfall patterns during the season, in which sufficient rainfall occurred at timely intervals.

Results discussed were obtained during the first year of a three-year study. In the following years, the study will be repeated, with additional testing of scheduling models, and additional agronomic measurements collected to better characterize plant and environmental conditions.

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