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Yield Response to Variable Rate Irrigation in Corn

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Abstract

To investigate the impact of variable rate irrigation on corn yield, twenty plots of corn were laid out under a center pivot variable rate irrigation (VRI) system in an experimental field near Stoneville, Mississippi. The VRI system is equipped with five VRI zone control units, a global positioning system (GPS) receiver, and computer software. Each zone control unit controls the duty cycle of the sprinklers in the zone to realize variable rate water application across the pivot lateral. The GPS receiver determines the pivot position for identification of the control zone in real time. Supplemental irrigation was scheduled based on evapotranspiration (ET) estimates. A randomized complete block design was used in this study, with five irrigation rate treatments (0, 50%, 75%, 100%, and 125% of the rate determined using the Arkansas Irrigation Scheduler) and four replications. During the growing seasons in 2012 and 2013, VRI prescriptions were created based on the experimental design, and wirelessly uploaded to the system to apply varying amounts of water to each plot. The corn was machine harvested for yield. Results indicated that effect of irrigation rate on yield was not significant in 2012 and was significant in 2013. The treatment of 125% irrigation rate had the highest yield for both years. No significant yield difference between treatments in the 2012 season could be due to the sufficient rainfall in that summer. The ET estimates used in the irrigation scheduling might be lower than actual water demand of the corn crops for a higher yield.

Keywords: center pivot, corn, Mississippi Delta, variable rate irrigation, yield

1. Introduction

The Mid-South US typically receives precipitation of about 130 cm per year. However, only about 18% of the precipitation occurs from June to August. Additionally, the precipitation patterns in summer frequently include heavy rainfall events that increase runoff from cropland with only a small amount of rainfall absorbed into the soil profile. Uncertainty in the amount and timing of precipitation becomes one of the most serious risks to producers in the Mid-South. Studies have shown that supplemental irrigation in this humid region could increase crop yield and reduce crop production risk (Cassel et al., 1985; Boquet, 1989; Sui et al., 2014). In recent years, producers in this region have become increasingly reliant on supplemental irrigation to ensure adequate yields. About 90% of irrigation water in the region is pumped from the Mississippi River Valley Alluvial Aquifer. Increasing groundwater withdrawal is resulting in a decline in aquifer levels across the region (Powers, 2007).

Corn is one of the most important cereal crops. Corn grain can be used for human food, animal feed, and pharmaceutical and industrial products. The United States is the largest producer of corn in the world. In the last decade, due to the more favorable prices for corn and soybeans, farmers in the Mid-South have shifted their land from other crops such as cotton, to corn and soybean, increasing corn acreage dramatically. More than 50% of corn in this region is irrigated, with about 90% of the irrigated corn furrow irrigated and the remainder under center pivot irrigation equipment. Compared with furrow irrigation, center pivot irrigation provides higher water application efficiency with less runoff and higher application uniformity. However, producers often consider the improvements associated with pivot irrigation to not be significant enough to justify the higher pivot equipment cost. As water issues in agriculture have been a focus for local governments and organizations, more farmers in the region are realizing the necessity of seeking water-saving technologies for sustainable agriculture.

Careful water management is required to optimize farming profits. Irrigation scheduling tools are available for farmers to schedule irrigation events to keep soil water sufficient for plant use but avoid saturating soil with water. Cassel et al. (1985) evaluated the effect of supplemental irrigation in a humid environment on corn production. The supplemental irrigation in the study was scheduled using a computer-based water balance model and tensiometer measurements. Results showed that the irrigation scheduling methods could greatly increase the yield in drier years, while the yield improvement was small in wetter years (Cassel et al., 1985). In a study of corn yield response to deficit irrigation in the US Great Plains, the yield increased linearly with seasonal irrigation water amount, but the relationship varied by year (Payero et al., 2006). Vories et al. (2009) reported a 3-year study on response of irrigated corn in the US Mid-South. Subsurface drip irrigation methods were employed with three irrigation levels: irrigation replacing 100% and 60% of estimated daily water use, and no irrigations. Significantly lower grain yield for the non-irrigated treatment was observed in one drier year. However, no significant difference between the two irrigated treatments was detected in any year during the study period. Stone et al. (2010) used a center pivot variable-rate irrigation system to investigate corn yield response to site-specific applications of water and nitrogen fertilizer. Three irrigation regimes (non-irrigated, 75% and 150% of the base rate) were used in the study. Results showed all three irrigation treatments were significantly different for one year, but the yield for the 75% and 150% treatments did not significantly differ in another two years.

The alluvial soils in the US Mid-South are often highly variable, with alternating layers of sand and clay. Soil physical properties in the region, especially in the Mississippi Delta, can vary significantly within a single field (Cox et al., 2006; Thomasson et al., 2001) resulting in differing storage capabilities and amounts of water available to the crop, creating challenges in crop water management. Plant growth status also varies considerably within a field. Plants in one location may need more water than plants in another location in the field. Treating the plants differently based on their needs is required for optimizing crop yield and quality. Precision agriculture technologies make it possible for farmers to adjust production inputs site-specifically to address spatial variability of the soil and plants in a field. Sprinkler irrigation systems equipped with variable rate irrigation (VRI) controls are now commercially available. A VRI system is capable of delivering the desired amount of water to specific locations in the irrigated area (LaRue & Evans, 2012).

Objectives of the study were to evaluate corn yield response to variable rate irrigation in a humid region and gain experience in creating prescriptions for precision irrigation management.

2. Materials and Methods

2.1 Experimental Design

The experiment was conducted in a field at the Research Farm of the United States Department of Agriculture (USDA), Agricultural Research Service (ARS), Crop Production Systems Research Unit in Stoneville, Mississippi (latitude: 33°26′30.86″, longitude: -90°53′26.60″) in 2012 and 2013. Silt loam was the predominant soil type in this field. There was about a 1% slope from the west end of the field to the east. No crops were grown in this field for several years before it was used for this study starting in the 2012 season. The study area was under the coverage of a center pivot irrigation system (Figure 1), and occupied one-quarter of the pivot's full circle. A randomized complete block design was developed with 4 blocks and 5 irrigation rate treatments resulting in 20 plots in total. Irrigation treatments consisted of 0% (non-irrigated), 50%, 75%, 100%, and 125%, where 100% treatment represented the irrigation rate that was calculated using a computer-based water-balance model and the application rates of the other treatments were scaled based on their percentages. An irrigation rate treatment was randomly assigned to each plot within a block, with a plot size of about 0.2 ha each. A 15 m by 15 m area inside each plot was identified as a sampling area, and data collected from the sampling area of a plot were used to represent that plot in the data analysis. A 3 m-wide alley was cut to separate the blocks. Layouts of the experimental plots in the 2012 and 2013 seasons are illustrated in Figure 2.

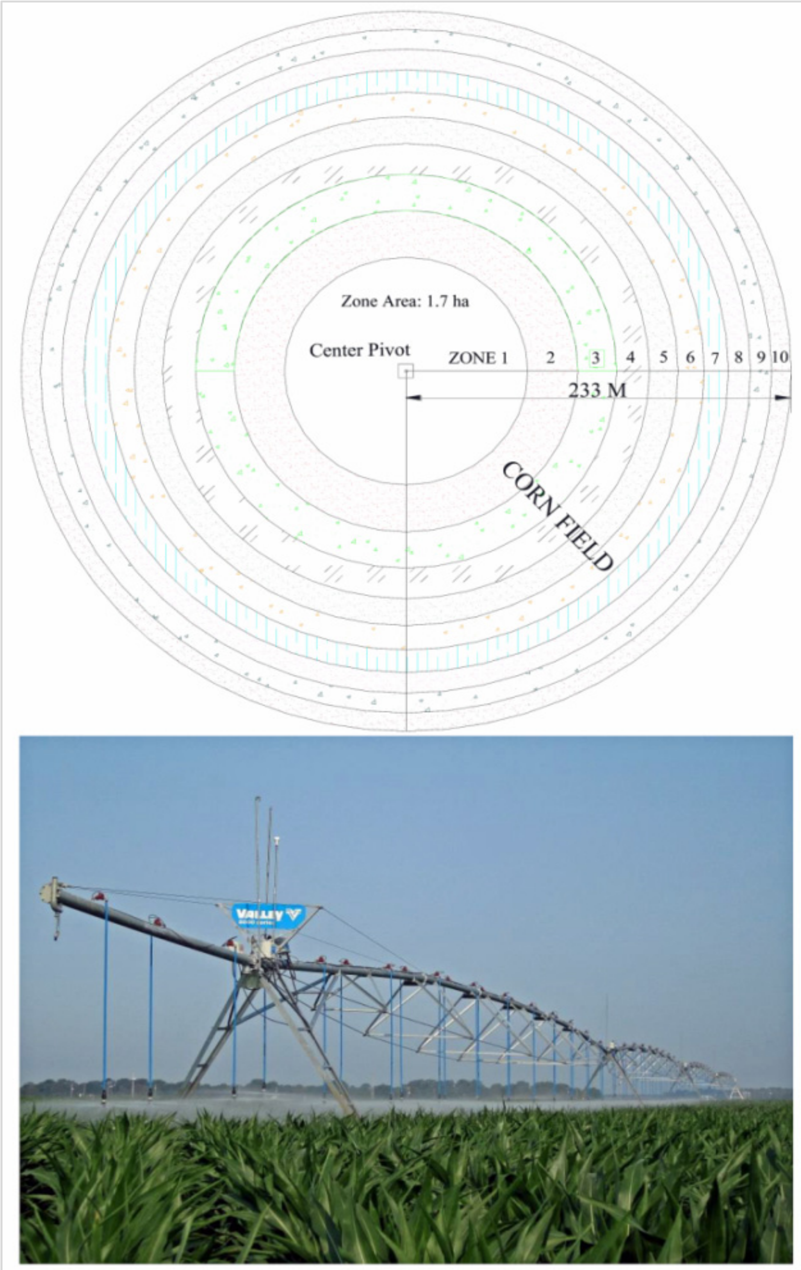

Figure 1. Center pivot variable rate irrigation system used to deliver different amounts of water to the experimental plots based on the experimental design. In the top portion of this figure, ten control zones of the variable rate irrigation system are indicated using hatched areas. Size of each control zone was 1.7 ha

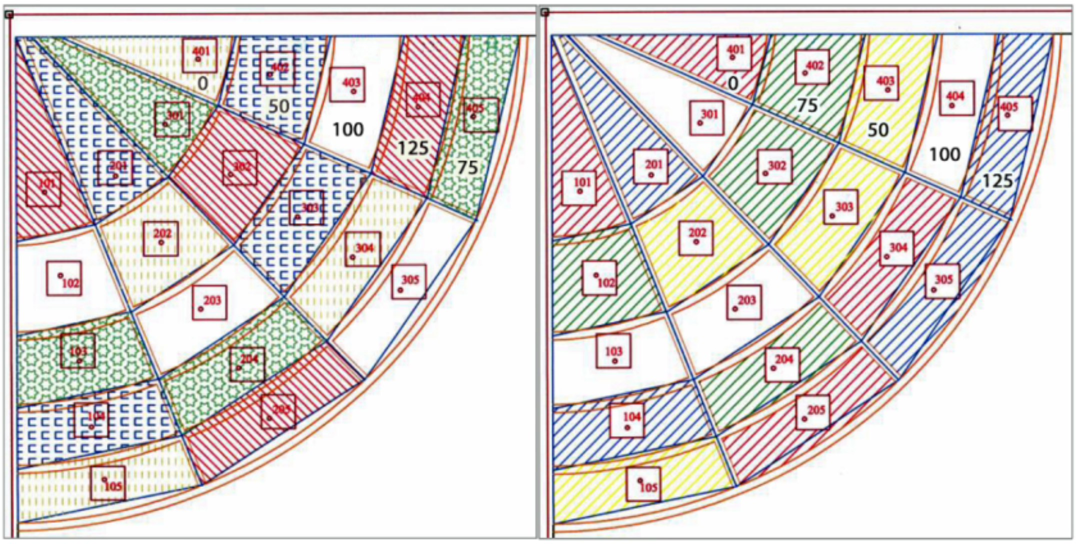

Figure 2. Experimental plot layout in the seasons of 2012 (left) and 2013 (right). The numbers 0, 50, 75, 100, and 125 in the plots indicate the assigned treatments. Plots with the same hatch pattern had the same treatment. The numbers in the center of red boxes were the plot numbers

2.2 Field Management

A center pivot variable rate irrigation (VRI) system was employed in this study (Figure 1). The irrigation system consisted of a Valley Standard Pivot 8000 coupled with the Valley VRI zone control package (Valmont Irrigation, Valley, NE, USA). Field tests showed that this center pivot VRI system had a coefficient of uniformity (CU_H) of 86.5% with constant rate application and 84.3% with variable rate application (Sui and Fisher, 2015). The system was configured in 4 spans with a total length of 233 m. Sprinklers along the length of the center pivot were divided into 10 control zones, with each zone covering the same surface area of the field. The Valley VRI zone control package included 5 VRI zone control units, solenoid valves, a GPS receiver, and computer software. Each VRI zone control unit controlled the duty cycle of the sprinklers in two independent zones by turning electric solenoid valves on and off to achieve desired application depths in individual zones. The GPS receiver determined the pivot's position and location in the field for identification of control zones in real time. VRI prescriptions were created using the software provided with the VRI system. In this research, VRI prescriptions were written to apply various amount of water at the experimental plots according to the treatment assignment.

In the 2012 season, corn variety P1184YHR (DuPont Pioneer, Johnston, IA) was planted on April 10. Nitrogen (N) was applied at a rate of 280 kg/ha using a side knife drill 31 days after planting (DAP). In 2013, Pioneer 33N58 seed was selected and planted on March 21. Using the same application method, a total of 291 kg/ha N was applied, split into two applications. The first application of 67 kg/ha occurred 47 DAP, and the second application of 224 kg/ha at 68 DAP. Plant density was about 90,000 plants/ha for 2012 and 2013.

From April to August, the total precipitation was 535 mm in 2012 and 504 mm in 2013 (Figure 3). There was 97% more rainfall in 2012 season than 2013 in June and July, during which time corn plants were more sensitive to water stress (Eck, 1986; Lamm & Kheira, 2009). Based on ET estimates determined using an irrigation scheduling program, five irrigation events were scheduled from May 25 to August 1 in 2012, with a total depth of 127 mm of water applied to the 100% treatment. Total water depth of 152 mm was applied to the 100% treatment in six irrigation events from June 20 to August 5 in the 2013 season. Water application depth with 100% treatment was 25.4 mm for each irrigation event in both seasons.

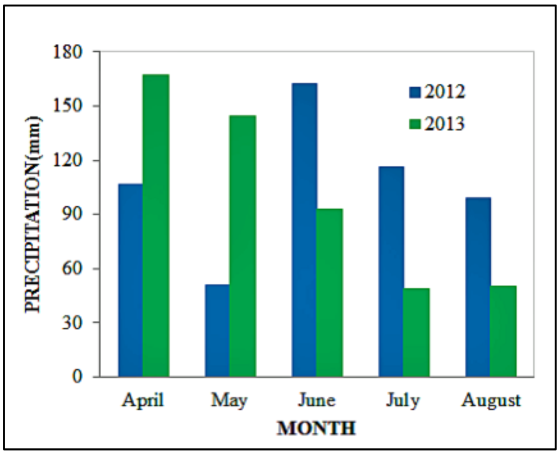

Figure 3. Precipitation distribution during the corn growth seasons in 2012 and 2013

2.3 Irrigation Scheduling

Irrigations were scheduled using the Arkansas Irrigation Scheduler, a computer-based water-balance model developed for irrigators in the Lower Mississippi Delta region of the USA (Cahoon et al., 1990). The scheduling program used a simple water-balance model to estimate a daily soil-water deficit. The model estimated soil-water deficit as the difference between water incoming, in terms of precipitation and irrigation application, and outgoing, in terms of crop evapotranspiration. The program output the daily soil-water deficit, as well as a projection of the deficit for the next few days. Each day of the growing season, the current daily soil-water deficit was estimated and compared to the allowable deficit, and a decision was made whether or not to irrigate. An allowable deficit of 5 cm was selected following guidance from the program based on soil type, crop, and irrigation system.

The original version of the scheduling program required the user to enter only daily values of maximum air temperature, precipitation, and irrigation amount. The program then calculated reference ET (ET_o) using an empirical relationship based on air temperature. The program was later updated (Vories et al., 2005) to allow the user to directly enter daily values of reference ET (ET_o), rather than use the empirical air temperature-ET_o routine. The updated version of the scheduler was used in this study, with ET_o values determined using the FAO-56 reference ET method (Allen et al., 1998) based on weather data collected at a nearby weather station operated by Mississippi State University (http://msucares.com/weather/). Crop ET (ET_c) was then estimated using the FAO-56 ET_o values and the scheduling program's built-in crop coefficient functions.

The program recommended that the user enter an estimate of effective, rather than total, precipitation, but offered no built-in routines or guidance for determining the effective amount. For the VRI study, effective precipitation, P_e, was estimated using the NRCS (Natural Resource Conservation Service) runoff curve number method (NRCS, 1986). The NRCS method estimated the amount of runoff that would occur during a rainfall event based on soil type and land use. Effective precipitation was then calculated by subtracting the estimated amount of runoff from the total precipitation.

2.4 Data Collection and Analysis

The corn was harvested on August 16 in the 2012 season and on August 27 in the 2013 season. In 2012, the entire corn field was harvested using a John Deere combine harvester. A yield monitor installed on the combine was used to record the yield data, which included the latitude and longitude coordinates of each point within the field and the yield associated with that point. The yield data were processed using ArcGIS 10.2.1 software (Esri, Redlands, CA). The yield values of the points within each sampling area were extracted, and an average of these yield values was calculated to represent the yield of that plot. In 2013, the crops in the sampling areas were harvested using a 4-row small-plot harvester equipped with a load-cell weighing system. Corn weight provided by the system was used to determine the yield of the plot. The yield data were then analyzed using the PROC GLIMMIX procedure (SAS Institute Inc., Cary, NC) to determine the effect of the irrigation rate on the yield. Combining the data from both years, an ANOVA was performed with years and irrigation rates as fixed effects and blocks with years as a random effect.

3. Results and Discussion

Figure 4 shows the corn yield map from the 2012 season. From the yield map, it was difficult to visually identify yield difference between the treatments. The ANOVA with the average data of 2012 and 2013 seasons indicated that the effect of irrigation rate on yield was significant ($p = 0.0064$), however, the effect varied from year to year. The effect of irrigation rate on yield was not significant in 2012 ($F = 0.91$, $p = 0.48$) and was significant in 2013 ($F = 5.96$, $p = 0.0018$). Table 1 shows the yield means and the results of pairwise comparisons of these means. For the year 2012, the yield ranged from 10,586 kg/ha to 12,836 kg/ha. Though the yields for all irrigated treatments were higher than the non-irrigated treatment, the yield was not significantly different between any treatments. Corn yield is very sensitive to water stress during the flowering and reproductive stages (Eck, 1986), which normally occur in the months of June and July in the Mid-South region. Due to the occurrence of sufficient rainfall in the water sensitive growth stages in 2012, based on the soil moisture measured using soil moisture sensors the plants were under minimal water stress, resulting in no significant yield difference between treatments in the 2012 season.

In 2013, the yield varied between 10,920 kg/ha to 14,963 kg/ha. The yield from the 125% treatment was significantly higher than that of the non-irrigated, 75%, and 100% treatments. The yield for the 125% treatment was 7.1% higher than the yield for the 50% treatment, but the difference was not statistically significant. The yield of the 75% treatment was significantly lower than the yield associated with the 50% and 100% treatments. For both seasons, the highest yield occurred with the 125% treatment. This could mean that the ET estimates used in the irrigation scheduling in this study were underestimated and that the corn crops could have benefitted from more water to produce a higher yield. Figure 5 shows a plot of the yield versus the irrigation rate. There was a weak trend showing corn yield increasing with an increase in irrigation rate.

It was noted that the yields among the observations in the non-irrigated, 100%, and 125% treatments had larger standard deviations than those in the 50% and 75% treatments, which signified that the yield with these treatments varied in a wider range (Table 1). This could be an indication that the crops under these treatments had experienced some water stress during a crucial phase. In combination with soil properties, even small amounts of water applied to the crops could introduce large yield changes during such crucial stages. It could be worth undertaking further reaseach on this phenomenon for developing deficit irrigation scheduling strategies in the humid region.

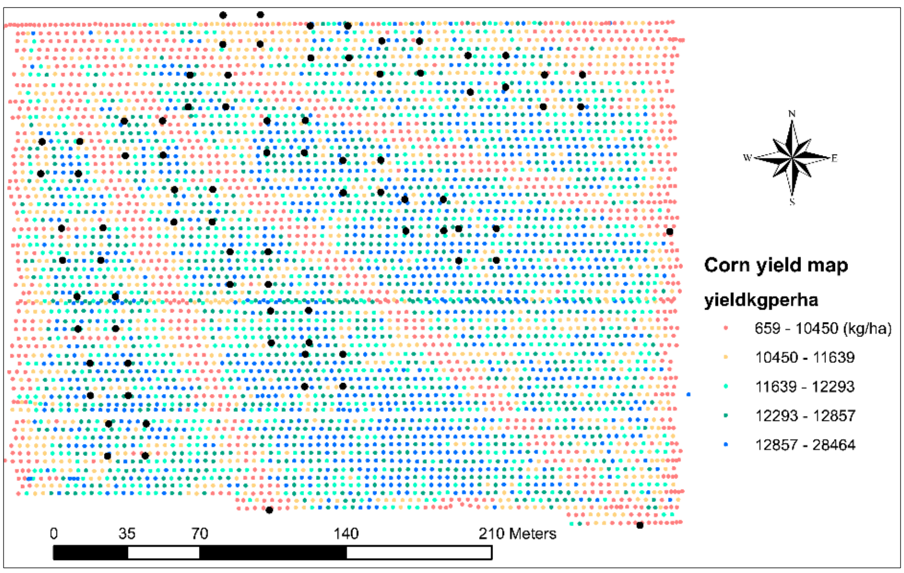

Figure 4. 2012 corn yield map generated using the yield monitor data. The black dots indicate the corner points of the sampling areas

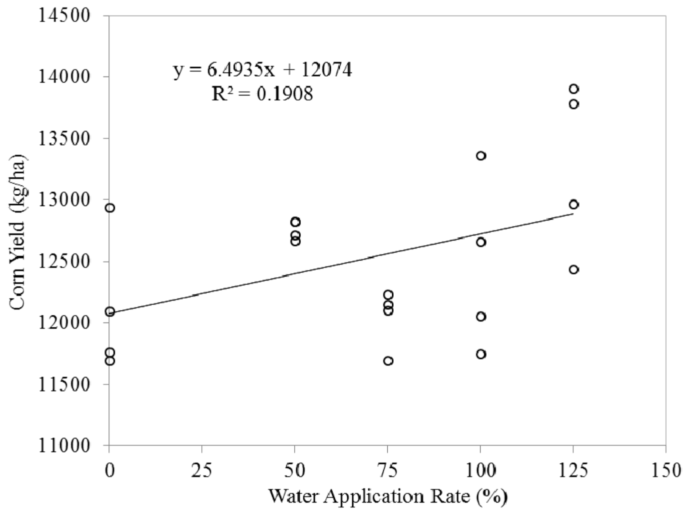

Figure 5. Average yield of each plot from the 2012 and 2013 seasons versus the irrigation water application rates

Table 1. Corn yield means associated with various irrigation rates (LSD = 955 kg/ha)

Irrigation Rate (%)	2012		2013		Two-Year Average	
	Yield mean* (kg/ha)	Std dev (kg/ha)	Yield mean* (kg/ha)	Std dev (kg/ha)	Yield mean* (kg/ha)	Std dev (kg/ha)
0	11808[a]	880	12436[b,c]	1135	12122[b,c]	571
50	12417[a]	197	13095[a,b]	316	12756[a,b]	77
75	12212[a]	323	11873[c]	516	12042[c]	240
100	11887[a]	546	13021[b]	918	12454[b,c]	712
125	12516[a]	304	14026[a]	1228	13271[a]	694

Note. * Means not followed by the same letter in each column differ significantly from one another based on LSD value at $p \leq 0.05$.

4. Summary and Conclusions

VRI technologies are able to site-specifically apply irrigation water at variable rates within the field to adjust the temporal and spatial variability in soil and plant characteristics. Understanding of crop yield response to various irrigation rates is required in VRI practices. Effect of irrigation water application rate on corn yield was studied with a center pivot VRI system for two years in a humid region. Supplemental irrigation rate of experimental plots was scheduled based on ET estimates. The VRI system varied irrigation water application depth to the plots by changing the duty cycle of ten groups of sprinklers installed along the length of the center pivot. Corn grain yields from five irrigation rate treatments were assessed in the 2012 and 2013 seasons. Effect of irrigation rate on yield was not significant in 2012, but was significant in 2013. There was 97% more rainfall in the 2012 season than in 2013 in June and July, at which time corn plants were more sensitive to water stress. No significant yield difference between treatments in the 2012 season could be due to the sufficient rainfall during that summer. The treatment with the highest irrigation rate had the highest yield for both years. This suggests that the ET estimates used in the irrigation scheduling might be lower than actual water demand of the corn crops for a higher yield.

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