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AGRONOMY & SOILS

A Retrospective Review of Cotton Irrigation on a Production Farm in the Mid-South

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ABSTRACT

The water table of the primary irrigation source for agriculture in the Lower Mississippi River Basin is declining at an alarming rate. Irrigation practices that sustain cotton lint yields and reduce irrigation water use include adoption of termination guidelines based on plant growth stage and weather conditions. Production records from a large northeastern Arkansas cotton farm were examined to gauge how well a plant maturity-based irrigation termination guideline (final irrigation at 350 Growing Degree Days (60°F base) following crop cutout) was followed. Irrigation logs and yield records from the producer plus plant monitoring data from the farm's crop advisor were used to evaluate irrigation practices in 70 field entities over eight production seasons. Results indicate that irrigation termination timing for furrow-irrigated fields generally occurred prior to the termination guideline. Adherence to the termination guideline allowed the producer to reduce late season pumping. These results are encouraging given that yields from the studied fields were above county averages for all years studied, which spanned wet to dry conditions. Nearly twice the amount of water was applied in furrow-irrigated compared to pivot-irrigated fields, yet lower average yields were produced in furrow-irrigated fields in six of the eight years. Furrow-irrigated fields had higher yield variability compared to fields with pivot irrigation. These results suggest that conversion of furrow irrigation to pivot irrigation likely would result in increased productivity and reduced water use, and that use of plant-based irrigation termination guideline could reduce the need for costly, late season pumping without a yield penalty.

Arkansas ranked third among the US for cotton lint and cottonseed production in 2010 (McGraw et al., 2011), with approximately 30% of cotton grown in the Mid-South. Even with recent reductions in overall cotton production due to price fluctuations and favorable grain prices, it is still a vital part of the Mid-South economy.

Arkansas is a water-rich state that receives more than 1270 mm (50 in) of rain annually. Though precipitation is abundant in the region, the timing and quantity might not coincide with specific agricultural needs. In response to a significant drought in 1980 and an increased aversion to risk on the part of lenders, Arkansas producers expanded adoption of irrigation with a 20% increase in irrigated acres between 1978 and 1982 and a 121% increase between 1978 and 1997 (NASS, 1997).

Approximately 11.6% of the more than 1.62 million ha (4 million acres) of irrigated cropland in Arkansas was planted in cotton in 2007 (NASS, 2008). Of the 234,175 ha (578,660 acres) of cotton harvested in Arkansas in 2007, approximately 90% was irrigated. More than 60% of the irrigated cotton employed furrow irrigation and the remaining 40% used pivot irrigation. Cotton irrigation across the Mid-South cotton production region defined as eastern Arkansas, western Mississippi, southeastern Missouri, the majority of Louisiana, and far western Tennessee, has a similar breakdown by irrigation method. However, of the harvested 548,385 ha (1.36 million acres) of cotton in 2007 in this region, roughly 72% was irrigated (NASS, 2008).

The primary irrigation water source in Arkansas and the Mid-South is the Mississippi River Valley Alluvial Aquifer, hereafter referred to as the alluvial aquifer. In Arkansas, approximately 80% of irrigation water comes from groundwater (NASS, 2008). Records of pumping from the alluvial aquifer in Arkansas began in the early 1900s. In 2009, the alluvial aquifer in Arkansas was pumped at 21.5 million $m^3 d^{-1}$ (5680 million gal d^{-1}) but the sustainable yield estimated by the Arkansas Natural Resources Commission is approximately half of that value (Fugitt et al., 2011). It is estimated that 96% of the water withdrawn from the aquifer is pumped for agriculture. Several counties

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in Arkansas have been designated as critical groundwater areas as a result of the pumping and limited recharge of the aquifer. In 2010, the depth to water in the alluvial aquifer was deepest in the Lonoke/Prairie County area and to the west of Crowley's Ridge in Poinsett, Cross, and Craighead counties (Fig. 1). Groundwater depletion of the Mississippi Embayment (which includes the alluvial aquifer and the middle Claiborne aquifer) from 1900 to 2000 was 117.6 km^3 and from 1900 to 2008 increased to 182.0 km^3 (Konikow, 2013). Out of the 40 major aquifers studied in the US (excluding Alaska), the rate of depletion in the Mississippi Embayment was second only to the Ogallala system in the High Plains (Konikow, 2013).

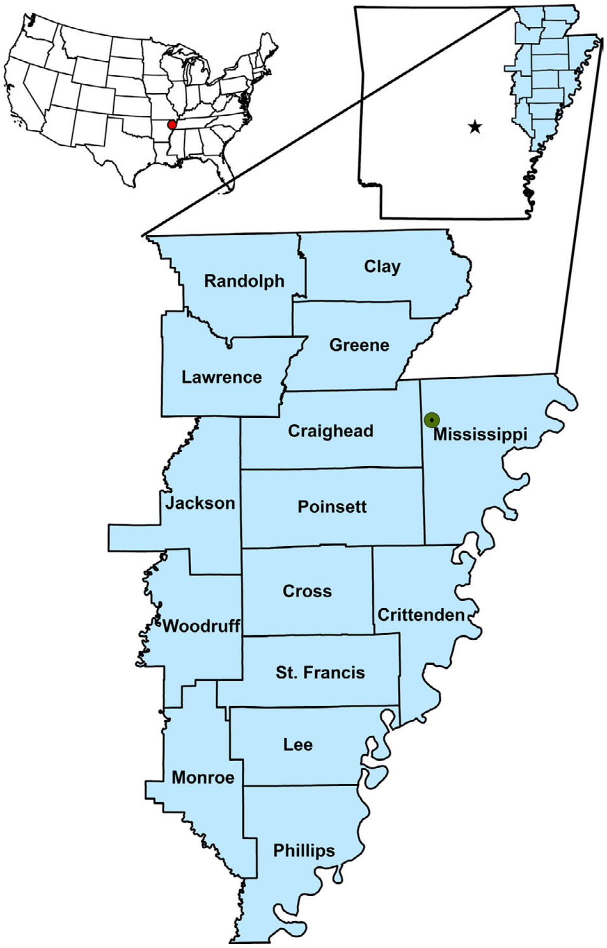

Figure 1. Study site located in Mississippi County, northeastern Arkansas.

In northeastern Arkansas east of Crowley's Ridge, the alluvial aquifer has not experienced the same reduction in base water level as the west side of the ridge due in part to recharge from the Mississippi River (Schrader, 2010). However, two depressions that were not evident in 2006 were evident in the 2008 mapping of the potentiometric surface and both are located in this area. One of these areas is located on the border between Craighead and Mississippi counties and the other at the border between Cross and St. Francis counties (Schrader, 2010).

The reduction of readily accessible irrigation water will force producers to go deeper into the alluvial aquifer or into deeper formations for irrigation, which will increase production costs and have long-term impacts on water supply. Practices and guidelines that reduce water use while maintaining yields are a vital part of commodity production. As profit margins are reduced, minimizing production costs through the incorporation of research findings should propel producers into a sustainable and profitable future. This is especially true in water management of irrigated crops, including cotton, in Arkansas due to the documented declines of the primary irrigation source.

Early research on optimizing the timing of irrigation termination was confounded by the many factors that affect a cotton crop (Unruh and Silvertooth, 1997). In 2011, Vories et al. published the findings from an 8-yr project, funded by Cotton Incorporated that evaluated use of plant-based cues for final irrigation timing. These cues, developed initially for use in timing insect control termination and defoliation, are based on the maturity of the last cohort of fruit (bolls) that economically contribute to harvestable yield (Bernhardt et al., 1986; Bourland et al., 1992). To determine flowering date of the last effective boll population, defined as physiological cutout, crop managers employ a simple plant sampling protocol to monitor the progression of flowering. They make weekly counts of the uppermost, first-position white flower on the plant main stem, termed nodes above white flower (NAWF). Research has shown that Mid-South cotton has reached physiological cutout when plants average NAWF = 5 (Bourland et al., 1992). Maturity of that cohort of bolls is then quantified using a running total of heat units accumulated following cutout. Heat units, often referred to as Growing Degree Days, are calculated using the base temperature for cotton, 60°F (15.6°C), expressed as DD60s. For simplicity, DD60s are calculated by subtracting 60 from the mean daily temperature, an average of daily maximum and minimum air temperatures. There are no upper or lower temperature thresholds for the heat unit calculation, and negative heat units are set to zero for that day.

Commercial crop advisors in the Mid-South routinely monitor NAWF for insect control termination decisions, following published Cooperative

Extension guidelines. For example, University of Arkansas recommendations suggest control termination for fruit feeding pests ranging from 250 to 450 DD60s after cutout depending on pest species (Studebaker et al., 2013). Additional management guidelines suggest defoliation at 850 DD60s after cutout (Oosterhuis et al., 2008). These and other plant and weather-based management guidelines were components of the COTMAN Expert System (Bourland et al., 2008; Danforth and O'Leary, 1998).

Because pumping costs associated with late season irrigation are typically the most expensive due to the increase in depth to groundwater, timely irrigation termination practices might reduce overall production costs. Vories et al. (2011) suggested the latest date that furrow irrigation could be expected to produce profitable yields in the northern portion of the Cotton Belt was 350 DD60s after cutout. Successful large-scale adoption of this proposed guideline, could improve irrigation water-use efficiency, enhance crop earliness, and improve farm profits. To gauge the need for educational efforts to inform and instruct producers on adoption of the proposed plant-based irrigation termination guideline, it would be helpful to know how current termination practices compare to the proposed guideline.

In the current study, we examined production records from a large northeastern Arkansas cotton farm to determine how well the plant-based irrigation termination guideline was followed for furrow- as well as pivot-irrigated production. Another study objective was to characterize historic and current irrigation practices for both furrow- and center pivot-irrigated cotton. This information will be critically important for long-term management planning given the extraordinary rate of groundwater depletion in the alluvial aquifer.

MATERIALS AND METHODS

Study Site. This study took place on Wildy Family Farms, a multi-generational farming operation in Mississippi County near Manila, AR (www.wildyfamilyfarms.celect.org) (Fig. 1). The county is bordered to the east by the Mississippi River and to the north, south, and west by other agricultural counties. Mississippi County has produced the majority of the cotton in the state for the past several decades, accounting for 20 to 25% of Arkansas cotton production.

The data used for the present analysis came from four sources: meteorological information collected from a nearby experiment station, irrigation logs and yield data from the producer, and plant monitoring data from the farm's private crop advisor. Although many farmers do not keep records with enough detail to determine past irrigation dates for individual fields, those records were available from Wildy Family Farms. The Wildy family has a long history of early adoption of new technology and of collaborating with industry, USDA, and university research as well as extension research and demonstration projects. This includes research results reported by Vories et al. (2011).

Seventy field entities covering approximately 2997 ha (7405 acres) were analyzed during eight production seasons from 2005 through 2012. Field entities were determined by irrigation source because one pump and motor system can service one or multiple fields. The study sites consisted of 27 furrow-irrigated and 43 pivot-irrigated field entities, with 82% of the acreage in pivot-irrigated fields.

Cotton was planted mid-April through mid-May, with the most common dates of planting occurring between the last week of April to the first week in May. There were delays in 2009 and 2011 because of wet spring conditions. There was little difference in the planting date when comparing furrow- and pivot-irrigated field entities.

Meteorological Data. A weather station located 23 km (14.3 mi) from the headquarters of Wildy Family Farms and managed by the University of Arkansas Northeast Research and Extension Center (NEREC) located in Keiser, AR was set to collect air temperature and precipitation data on a daily basis. Monthly values of maximum, minimum, and mean temperature and total precipitation were generated from daily data during the study period and analyzed to characterize the meteorology of each of the study years.

Irrigation Logs. The producers documented irrigation timing on more than 70 field entities between 2005 and 2012, covering 2997 ha (7405 acres). Furrow irrigation documentation was not available for 2005 and 2007. The documentation of both types of irrigation systems was similar and consisted of a spreadsheet with site names and dates for 2 wk per page. The date the pump was turned on, if the pump remained on for subsequent days, and when the pump was turned off was noted on the spreadsheet by hand. In addition, the amount of water applied was noted for the pivot-irrigated fields. It was assumed that the pivot irrigation systems completed one revolution per irrigation cycle.

Each pivot irrigation cycle took approximately 2.5 d per field. If a pump was noted as "on" for more than 4 d, an additional application of the set amount was added to the total. The water applied to each pivot-irrigated field was summed for each field entity and production season.

The amount of water applied to the furrow-irrigated fields was based on the number of days the pump was on (determined from the irrigation logs), flow-rate data from the pump, and field size. Flow measurements during the production season were measured at the pump location with a propeller style flowmeter (McCrometer, Inc., Hemet, CA; www.mccrometer.com) at several of the furrow-irrigated fields, and the average flow for these sites was 457.4 m^3 hr^{-1} (2015 gpm). For the measured sites, the amount of water applied ranged from 33 mm (1.3 in) to 117 mm (4.6 in). As a flow measurement for each field was not available and due to the wide range of measured values, a standard value of 76 mm (3.0 in) was used for this study based on suggested values for Arkansas by Hogan et al. (2007).

Plant Monitoring. Dates of physiological cutout were based on weekly plant monitoring of NAWF collected by the private crop advisors using COTMAN sampling protocols. Weather data were used to determine heat unit accumulation (DD60s) beyond cutout. The date each field reached the 350 DD60 past cutout threshold was recorded and compared to the date of final irrigation. The difference was reported in days with positive values indicating the final irrigation occurred prior to the recommended date and negative values indicating the final irrigation occurred after the recommended date.

Plant monitoring data were not available for 2005 and 2007 for the furrow-irrigated fields and for 2008 for both furrow- and pivot-irrigated fields.

Yield. Yield information was generated from field production reports for each field. Yield from field entities that were comprised of more than one field were area weighted. Yield data collected for all study fields during the 8-yr study were reported in pounds of lint per acre and converted to kilograms per hectare. Separate yield data from the rainfed portions of field entities (i.e., pivot corners) were available from six field entities in 2011 and 2012.

RESULTS AND DISCUSSION

Meteorological Conditions. Average annual precipitation of 1219 mm (48 in) was measured during the years of the study at the NEREC weather station. The precipitation data were broken into three general categories—wet, moderate, and dry (Fig. 2a). Annual precipitation in 2006, 2009, and 2011 was recorded as greater than 1370 mm (54 in) and was considered wet. 2007 and 2008 were considered moderate with annual precipitation between 1020 and 1370 mm (40-54 in). Precipitation in 2005, 2010, and 2012 was recorded as less than 1020 mm (40 in) annually and were considered dry.

In addition to annual precipitation, the rainfall during the growing season of May, June, July, and August is reported (Fig. 2b). Not surprisingly, wet years recorded high growing season precipitation of more than 480 mm (19 in), whereas the dry years ranged from 250 mm to 360 mm (9.9 to 14.1 in). During the 2007 growing season only 150 mm (5.9 in) was recorded, which was on par with 2012, a dry production year; fall and winter precipitation events brought the annual precipitation values closer to the average.

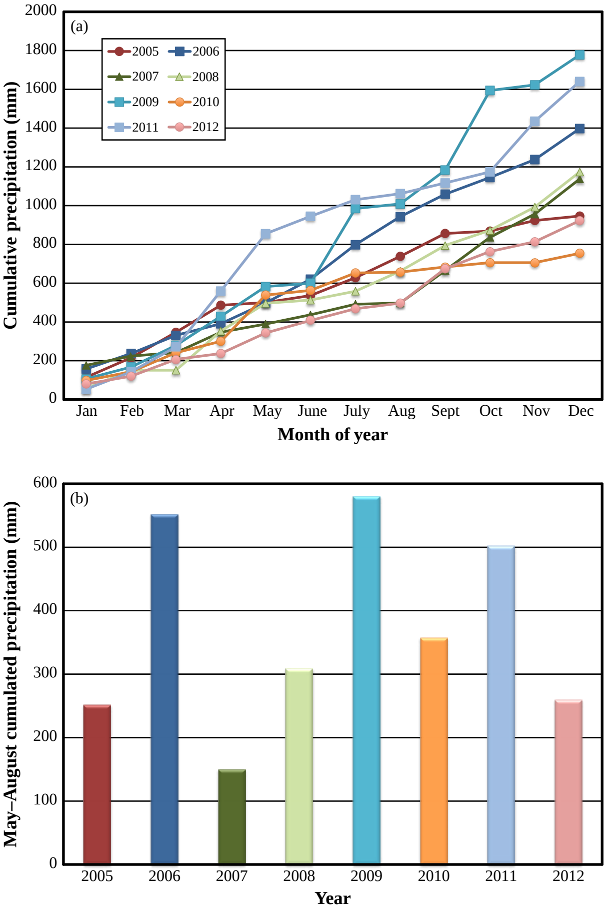

Figure 2. (a). Cumulative precipitation (mm) and (b). May to August cumulative precipitation (mm) from University of Arkansas Northeast Research and Extension Center, Keiser, AR for 2005 to 2012.

The average annual air temperature for the eight study years ranged from 15.6 to 17.8°C (data not included). The average maximum air temperature in June, July, and August, the principal irrigation period, ranged from 28.9 to 34.4°C. There was little year-to-year variability except for 2006 and 2009, when the average temperatures in the summer months were approximately 1.6 and 5.5°C cooler than the other years, respectively. This can be attributed to cloudy conditions from several precipitation events that occurred throughout the growing season of 2006 and 2009. Overall, 2005 to 2012 presents a variety of meteorological conditions, which allowed for a more complete representation of conditions encountered by producers in the Mid-South.

Irrigation Water. The data in Fig. 3 show applied irrigation water for the furrow- and pivot-irrigated fields. Average estimated water applied at the study site ranged from 602 to 770 mm (24 to 30 in) for the furrow-irrigated fields and 129 to 365 mm (5 to 14 in) for pivot-irrigated fields. There was little variation among individual fields within each year for a given irrigation system, suggesting the fields were irrigated based on general conditions and not determined by individual field conditions. This was supported by a small standard deviation from the means for the two irrigation systems, which averaged 160 mm (6.3 in) for furrow and 30 mm (1.2 in) for pivot. Given the heterogeneous soils common in the production area, the strategy of applying water in each field based on general conditions compared to individual field conditions might be too coarse a metric to determine irrigation and might reduce the effectiveness of the irrigation. Further improvements in irrigation management also could be made through the use of site-specific sensors to indicate irrigation needs and more widespread use of automatic control of the pump and motor systems.

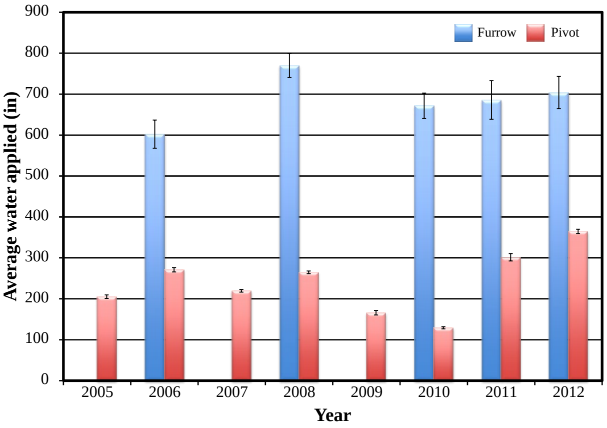

Figure 3. Irrigation water applied (mm) for 2005 to 2012 at (a) furrow- and pivot-irrigated study entities.

On average, more water was applied to the furrow-irrigated fields than the pivot for this study during all years. For the five years where data from both the furrow and pivot systems were available, the estimated percent difference between the average water applied (estimated for the furrow fields) ranged from 48 to 81% and averaged 61% more water applied for furrow irrigation. This difference is inherent in the efficiencies of how much water was available to the plant versus how much water was applied. In an eastern Arkansas study, irrigation application efficiency measured on producer's fields averaged 73% for furrow-irrigated cotton fields and 83% for sprinkler irrigation (USDA-SCS, 1987).

Irrigation Termination. Termination guidelines were generally followed, on average, within 2 wk at all sites (Fig. 4). In all study years when data were available, irrigation termination occurred, on average, before the guidelines suggested except for 2010. Irrigation was terminated on average 14, 9, 13, and 15 d earlier than the date that the accumulated DD60s reached 350 for the furrow-irrigated fields in 2006, 2009, 2011, and 2012, respectively (Fig. 4). Late season precipitation patterns contributed to the earlier termination in these years, especially in 2006.

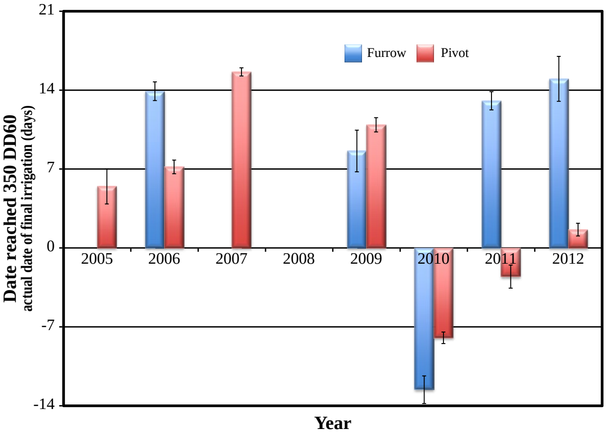

Figure 4. Mean number of days (and standard error) between the date 350 DD60s was reached and the actual date of final irrigation for furrow- and pivot-irrigated study entities.

The termination guidelines from Vories et al. (2011) were based on furrow-irrigated field research; however, the guidelines might yield similar trends for the pivot systems. In pivot-irrigated fields, irrigation terminated 5, 7, 17, 11, and 2 d earlier than the date that the accumulated DD60s reached 350 in 2005, 2006, 2007, 2009, and 2012, respectively (Fig. 4). In 2010, irrigation continued past the guideline date by 13 and 8 d for furrow- and pivot-irrigated fields, respectively and by 3 d for pivot-irrigated fields in 2011.

It is encouraging that irrigation did not continue beyond the eventual guideline in five of six of the years where furrow-irrigation data were available and that average yields from this producer were greater than county averages during all years studied. Also, irrigation costs at the end of the season are more expensive compared to the beginning of the season due to seasonal declines in groundwater. As more producers adopt this practice and continue to sustain yields, end of season pumping should decrease, which should contribute to a reduction in the pumping pressure on the aquifer.

Earlier termination of irrigation can act to limit late season re-growth of cotton, a perennial plant. Reducing the "rank" growth associated with late irrigations will reduce pest risks from insects attracted to high quality food in that rank growth. Additional benefits include reduced overall application rates of harvest aid materials needed for defoliation. Early termination can contribute to an earlier crop with timely harvest, enabling the producer greater flexibility in fall to prepare for the next cropping season.

Yield. The lint yield values were generally consistent during the study years with an 8-yr average of 1297 kg ha^{-1} (1158 lb acre^{-1}) and ranged from 1168 to 1424 kg ha^{-1} (1043 to 1272 lb acre^{-1}) (Fig. 5). The largest lint yields from the study were in 2007, with a maximum of 1880 kg ha^{-1} (1679 lb acre^{-1}) and average of 1424 kg ha^{-1} (1272 lb acre^{-1}). The 2007 crop season was a moderate year with little in-season precipitation and likely fewer production season cloudy days, which would contribute to increased yield (Zhao and Oosterhuis, 2000). Also, 2007 followed a relatively wet year and the early part of the year was characterized by average precipitation, which allowed for a wetter soil profile early in the 2007 season.

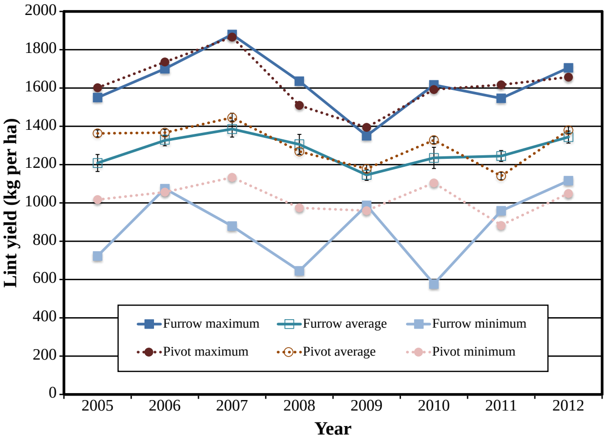

Figure 5. Maximum, minimum, and average (with standard error) lint yield (kg ha^{-1}) from furrow- and pivot-irrigated fields for 2005 to 2012.

Lint yield from pivot-irrigated fields is confounded due to the yield from the rainfed corners being included in the reported yield for the field entity. The corners constitute an average of 13% of the acreage. However, average lint yield from the pivot-irrigated fields was greater than furrow for 6 (2005, 2006, 2007, 2009, 2010, 2012) of the 8 yr studied. Only in 2005 was the pivot-irrigated yield statistically greater (p-value < 0.05) than furrow. The two years (2008 and 2011) when average lint yield was greater from the furrow-irrigated entities than pivot-irrigated included wet springs; yield differences were statistically significant (p-value < 0.05) in 2011 only. The field that yielded the least amount of lint was furrow-irrigated in 5 of the 8 yr.

Yield variability appears to be greater in furrow-irrigated entities compared to pivot-irrigated. This was manifest more readily during moderate and dry years with lower minimal yields in furrow compared to pivot, where yield from the pivot-irrigated entities ranged between 254 kg ha^{-1} (227 lb acres^{-1}) and 528 kg ha^{-1} (534 lb acres^{-1}), and averaged 351 kg ha^{-1} (313 lb acres^{-1}) more than than furrow-irrigated. In comparison, in the wet years and 2012, the minimum yield for furrow and pivot-irrigated fields were similar and within 75 kg ha^{-1} (67 lb acres^{-1}). Further evidence of higher variability in furrow- compared to pivot-irrigated entities was in the standard error of the mean of the yield. The standard error of the average of the furrow-irrigated yield was twice that of the pivot-irrigated yield. The reason for lower minimum yields from furrow irrigation during moderate and dry years is suggestive of incomplete irrigation in furrow entities during these conditions or fields being allowed to get too dry.

The impact on lint yield due to irrigation water applied was calculated from the rainfed portions of six fields during 2011 and 2012, where rainfed yield data were available. The average rainfed lint yield was 849 and 804 kg ha^{-1} (758 and 718 lb acre^{-1}) for 2011 and 2012, respectively. The yield gain due to irrigation water applied over rainfed yield ranged from 0.220 to 1.411 kg ha^{-1} mm^{-1} (5 to 32 lb acre^{-1} inch^{-1}) of irrigation water applied in 2011 and 0.760 to 1.852 kg ha^{-1} mm^{-1} (17 to 42 lb acre^{-1} inch^{-1}) of irrigation water applied in 2012. The average yield gain in 2011 was 0.750 kg ha^{-1} mm^{-1} (17 lb acre^{-1} inch^{-1}) and 1.367 kg ha^{-1} mm^{-1} (31 lb acre^{-1} inch^{-1}) of irrigation water applied.

Because rainfed yield data were unavailable for all fields, the average rainfed yield from the available data was applied to all of the study fields for 2011 and 2012 and resulted in similar trends to the six fields just described. The average gain from irrigation water applied for all of the study fields ranged from 0.088 to 2.425 kg ha^{-1} mm^{-1} (2 to 55 lb $acre^{-1}$ $inch^{-1}$) in 2011 and 0.397 to 2.072 kg ha^{-1} mm^{-1} (9 to 47 lb $acre^{-1}$ $inch^{-1}$) in 2012. The average yield gain achieved from irrigation water applied was 0.838 kg ha^{-1} mm^{-1} (19 lb $acre^{-1}$ $inch^{-1}$) in 2011 and 1.322 kg ha^{-1} mm^{-1} (30 lb $acre^{-1}$ $inch^{-1}$) in 2012.

Vories et al. (2007) studied irrigation water use efficiency for three years (2001-2003) in northeastern Arkansas cotton fields. Values from the well-watered plots were 0.68, 0.89, and 0.17 kg ha^{-1} mm^{-1}, for 2001, 2002, and 2003, respectively, and averaged 0.58 kg ha^{-1} mm^{-1} during the 3-yr study. These values are lower than those reported here due to the study site being on a clay soil type with lower yield potential. The low value from 2003 was attributed to a wet production season. In contrast, irrigated water-use efficiency in semiarid climates is often much higher due to production season precipitation severely limiting dryland yield (Ibragimov et al., 2007).

CONCLUSIONS

Roughly twice the amount of water was applied to furrow-irrigated entities studied compared to pivot-irrigated, though average lint yield was similar in six of eight years. Yield from furrow-irrigated fields was statistically greater in a wet year, whereas yield from pivot-irrigated fields was statistically greater during a dry year. It is the perception of many local producers that cotton production from furrow-irrigated fields is higher than for pivot-irrigated fields; this was only found in two of the eight years studied and significant in only one year. The confounding effect of rainfed corners, typically with lower yield potential, affects perception of growers on the relative effectiveness of irrigation methods. Furthermore, during dry and moderate precipitation in the production season, excluding 2012, minimum yields from furrow-irrigated fields were lower than pivot-irrigated fields by an average of 351 kg ha^{-1} (313 lb $acre^{-1}$). Variability in fields might contribute to this, but irrigation events might not be as effective in furrow-irrigated fields compared to pivot-irrigated during drier conditions due to soils crusting over in the furrow. Effectiveness of furrow irrigation applications in cotton is currently being researched in this region.

The plant-based irrigation termination guideline proposed by Vories et al. (2011) suggests little to no benefit to applying furrow irrigation applications after the crop has accumulated 350 DD60s from physiological cutout (NAWF = 5). Results from this study support that recommendation. Irrigation termination at and even prior to the guideline produced consistent yields that exceeded county averages during the eight years studied. Water levels in the alluvial aquifer decline through the season, making late season pumping the most expensive due to the depth to groundwater being at a seasonal maximum. The termination guideline was established for furrow-irrigated fields, but there appeared to be little or no yield penalty when the guideline was followed in pivot-irrigated fields. Irrigation termination in pivot-irrigated field entities was consistently later than furrow-irrigated by approximately 8 d on average. Because pivot applications are less, later termination in pivot-irrigated fields is consistent with expectations. A clear guideline for irrigation termination of pivot irrigation is needed for producers in the region.

Data analysis indicated irrigation events in both furrow- and pivot-irrigated fields were triggered on a schedule based on generalized weather conditions and not to individual field conditions. Possible refinements to irrigation needs might come to light with individual field sensors that indicate field-specific irrigation needs. If fully incorporated into production decisions, this information might impact how irrigation is implemented and ultimately impact water use and the alluvial aquifer.

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DISCLAIMER

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