Estimating the Impact of Delaying Irrigation for Midsouth Cotton on Clay Soil

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Abstract. *In many years, cotton producers in the Midsouth delay the first irrigation to allow time for other field operations such as pesticide and fertilizer application. This practice is especially common on clay soils that require several days to dry after furrow irrigation. However, the cost to the producer of delaying irrigation is not well understood. The objective of this research was to estimate the impact of delaying the first irrigation for cotton on clay soil to help producers make more informed decisions regarding irrigation timing. Cotton irrigation studies were conducted at the University of Arkansas Northeast Research and Extension Center at Keiser during the 2001 through 2003 growing seasons, with the cultivar PM 1218 BG/RR planted on a Sharkey silty clay (Chromic Epiaquerts) precision graded to approximately 2 mm m^{-1} slope. All plots contained four rows approximately 180 m long with a 97 cm row spacing and four-row border area left between each pair of plots. A well watered treatment was irrigated at a 50 mm estimated soil water deficit (SWD) based on the Arkansas Irrigation Scheduler. Irrigations for two delayed-irrigation treatments were initiated on the date of the second irrigation or third irrigation of the well watered treatment and then irrigated at a 50 mm estimated SWD. A nonirrigated check was included. Irrigations were ceased when open bolls were observed. Three-year-average yields decreased with delaying irrigation. There was a consistent trend for lower yield for each delay in the first irrigation; however, in 2003, the differences among all four treatments were not significant. The three-year-mean irrigation water use efficiency was higher for the well watered treatment than for either delayed-irrigation treatment; however, in two of the three years (2001 and 2003), the differences among the treatments were not significant. Gross revenues for the well watered treatment were numerically greatest each year; however, when the costs of irrigation were included, estimated net revenues for the well watered treatment were not always highest. A number of scenarios were investigated (e.g., different water sources, rented land), and even though two of the three years were wetter than normal, the delayed-irrigation treatments always had significantly lower estimated net revenues than the well watered treatment. Furthermore, the estimated net revenues for the delayed-irrigation treatments in each case were not significantly different from those of the nonirrigated treatment. When all other factors were held constant for rented farmland, the well watered treatment had higher estimated net revenues than the nonirrigated treatment for diesel cost < \$0.65 L^{-1} (\$2.47 gal^{-1}). A treatment with a delayed first irrigation, a fairly common practice on Midsouth cotton farms, was only more profitable than the nonirrigated treatment when diesel cost < \$0.19 L^{-1} (\$0.74 gal^{-1}).*

Keywords. *Cotton, Crop management, Crop production, Irrigation, Irrigation economics, Surface irrigation, Water management, Water use, Water use efficiency.*

Cotton (*Gossypium hirsutum* L.) is one of the major crops in each of the Midsouth states of Missouri, Arkansas, Tennessee, Mississippi, and Louisiana. The region has a subhumid climate, and irrigation has been a fairly recent addition to the production systems in those states. Since 1972, the USDA National Agricultural Statistics Service (USDA-NASS) has kept separate records for irrigated and rainfed cotton crops in Arkansas, Mississippi, and Louisiana. In 2005, these states combined 73% of the total harvested cotton hectares in the Midsouth and 21% of the total harvested upland cotton hectares in the U.S. (USDA-NASS, 2006). The irrigated portion of the combined crops in these three states increased from 3% in 1975 to 58% in 2005 and has remained over 50% in each of the years 2002 to 2005.

While the combined data from the three states indicate a consistent increase for yields of irrigated cotton above rainfed yields (average of 183 kg lint ha^{-1} during the 34-year period; USDA-NASS, 2006), many producers are concerned about the variability in irrigated cotton yields in the region. Examples of that variability are 1993 (764 kg ha^{-1}), 1995 (843 kg ha^{-1}), and 1998 (821 kg ha^{-1}), when three years in a six-year period had the lowest irrigated yields since 1981. This suggests that the negative impact of weather variability cannot all be overcome with irrigation. However, since stabilizing yields is often given as a principal reason for investing in irrigation, variability in irrigated yields is a major concern.

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While some improvement in yield stability could come through the development of new cultivars, short-term progress will probably have to come through improved irrigation management.

Water requirement for cotton varies throughout the growing season, with relatively low use during the vegetative period and rapidly increasing needs during reproductive growth. The water requirement decreases late in the year as bolls mature. Current University of Arkansas Cooperative Extension Service (CES) recommendations are to begin monitoring the soil moisture status of the crop at planting (e.g., tensiometers, water balance calculations) and maintain well watered conditions until bolls begin to open. Due to factors such as pesticide and fertilization application and preparing other crops on the farm, the first irrigation in cotton often comes later than recommended. Of course, the effect of such a delay will depend greatly on the weather conditions and the resulting field water status. Periods of drought are less likely early in the season, so rainfall will often prevent excessive stress from developing when an early irrigation is missed. Later in the season, the plants are using more water and the likelihood of drought is greater.

Although many researchers have studied the effect of differing levels of water stress on cotton, much of the work was done in arid regions where irrigation is essential for production. Garrot et al. (1988) reported an increase in yield with the number of irrigations, and Fangmeier et al. (1989) observed that seedcotton yields increased with the amount of water applied. Grimes et al. (1969) showed lint yield increasing with the amount of water applied, but then decreasing at higher levels of applied water.

Maximum yields usually corresponded to the lowest water-deficit stresses. Cudrak and Reddell (1988) showed seedcotton yields decreasing as the allowable water deficit increased, but in the Midsouth, Vories et al. (1991) did not observe differences among three treatments with different allowable deficits. Garrot et al. (1988) reported that the highest yields were associated with the lowest levels of stress at irrigation, and Reginato (1983) observed a linear increase in lint production as the seasonal average stress index decreased. Hearn and Constable (1984) determined that water stress reduced yield up to 40 kg lint ha^{-1}. Clark and Reddell (1986) and Reddell et al. (1987) found that plants could overcome yield reduction from early water stress when the growing season was sufficiently long. However, in the northern portion of the Midsouth, growing degree day (15.6° C base) accumulation slows greatly after August, and the additional growing season is often not available.

In the Midsouth, cotton can be produced without irrigation, and water stress often comes from excess as well as deficient water. The risks are exacerbated on clay soils, where limited internal drainage can lead to excessive waterlogging. Hodgson and Chan (1982) observed that increasing the inundation period on a cracking clay from 4 to 16 h reduced lint yields by 8%. While furrow irrigation in many large Midsouth fields can easily take 12 h or longer, rainfall shortly after an irrigation can increase the waterlogging period substantially.

Hearn and Constable (1984) stated, "Irrigation decisions are compromises between reducing the risk of water stress and increasing the risk of waterlogging." Producers often know they need to irrigate earlier, but they have little information on the cost of delaying irrigation. The risks associated with irrigating are well known, especially for furrow irrigation on clay, where the soil is slow to dry. Pesticide and fertilizer application may have to be delayed for several days after an irrigation until the soil dries sufficiently to support traffic without severe rutting or soil compaction. An estimate of the costs associated with waiting to irrigate would allow a more informed decision on what to do first. The objective of this research was to determine the impact, including the estimated cost to the producer, of delaying the first irrigation for cotton on clay soil.

Methods and Materials

Cotton irrigation studies were conducted at the University of Arkansas Northeast Research and Extension Center (NEREC) at Keiser (35° 40′ N, 90° 5′ W) during the 2001, 2002, and 2003 growing seasons to investigate the effects of delaying the initial irrigation. The cultivar PM 1218 BG/RR (Delta and Pine Land Co., Scott, Miss.) was planted on 29 May 2001, 21 May 2002, and 1 May 2003 with a John Deere 7100 planter (Deere & Company, Moline, Ill.) at approximately 13 seeds m^{-1} in 97 cm rows on a Sharkey silty clay (very fine, smectitic, thermic Chromic Epiaquerts) that was precision graded to approximately 2 mm m^{-1} slope. Ammonium nitrate was aerially applied in single pre-flower applications at rates of 143 kg N ha^{-1} in 2001 and 140 kg N ha^{-1} in 2002 and 2003. Soil tests indicated that no other fertilizers were required. CES recommendations were followed for weed and insect control (Bonner, 1995). All plots contained four rows approximately 180 m long with a 97 cm row spacing. The center two rows were harvested for yield determination in 2001; all four rows were harvested for yield determination in 2002 and 2003. A four-row border area was left between each pair of plots to reduce any effect of lateral movement of water during irrigation.

Treatments consisted of three furrow-irrigated treatments and a nonirrigated check (NI) in a randomized complete block design with four replications. A well watered treatment (WW) was irrigated at a 50 mm estimated soil water deficit (SWD) based on the Arkansas Irrigation Scheduler (Cahoon et al., 1990), hereafter referred to as the Scheduler. Irrigations for two "delayed" treatments were initiated on the date of the second irrigation (DELAY1) or third irrigation (DELAY2) of the WW treatment and then irrigated at a 50 mm estimated SWD. Irrigations were ceased when open bolls were observed, according to CES recommendations. The DELAY1 treatment represents the common situation where a producer chooses to wait to begin irrigating until most of the field operations are completed, whereas the DELAY2 treatment represents the situation where a producer planned not to irrigate a field and then reconsidered because of dry conditions.

The Scheduler calculates an estimated daily crop evapotranspiration based on estimated pan evaporation, a pan coefficient of 0.86, and a crop coefficient that varies from 0.2 to 1.0 as a function of crop age. Since only limited climatic data were available for most Midsouth locations, Cahoon et al. (1990) used regression analyses to estimate pan evaporation for six Midsouth locations based on day of the year, latitude, and daily maximum temperature. Keiser, Arkansas, was one of the six locations used in the regression analyses.

Counts of the number of plants per 3 m of row were made in several locations each year. Nodes above white flower

(NAWF) were counted weekly on ten plants per plot (five plants per plot in 2003) beginning soon after all plots were flowering and continuing until the average NAWF for all plots was less than 5, indicating physiological cutout (Bourland et al., 1992). Seedcotton was harvested on 8 October 2001, 17 October 2002, and 1 October 2003 with a Case IH 1822 two-row cotton picker. Seedcotton weights for each plot were determined with an instrumented boll buggy. An approximately 0.5 kg sample of seedcotton from each plot was ginned on a 10-saw laboratory gin without lint cleaners to determine gin turnout for lint yield calculations. The additional lint associated with irrigation was calculated as the difference between the yield from an irrigated treatment and the yield for the NI treatment in the same replication.

In this experiment, it was not possible to measure the water applied to individual plots. Therefore, net irrigation application was assumed equal to the estimated SWD on the day of irrigation, consistent with the assumptions for surface irrigation in the Scheduler (Cahoon et al., 1990). The Scheduler follows the assumption that surface irrigation will replace all the SWD. While the assumption will not be valid in all cases, it probably applied at this location. As a vertisol, cracks formed in the soil as it dried. The drier the soil, the deeper and wider the cracks became. The initial infiltration rate was very high until the cracks filled with water and then much slower afterward. Water moved laterally in the cracks and, following an irrigation, the soil appeared uniformly saturated.

Gross application was calculated as the net irrigation divided by an assumed application efficiency of 67.5%, the middle of the range for furrow irrigation from Solomon (1988). Although application efficiency was not measured in this study, 67.5% was considered an achievable value for producers in the region. Irrigation water use efficiency (IWUE) was calculated as the ratio of the additional lint yield to total estimated gross irrigation, as suggested by Howell (2000) and others.

Fiber samples from each plot were sent to Cotton Incorporated (Cary, N.C.) for high-volume instrument (HVI) fiber quality analysis. Cotton prices were calculated from the CCC loan schedule of premiums and discounts for upland and ELS cotton for the appropriate year (National Cotton Council, 2005, personal communication), based on the HVI data for each plot. Although the price schedule includes premiums and discounts based on length uniformity, none were applied in this study. Because the fiber was ginned on a laboratory gin, the length uniformity was probably greater than that of cotton that was commercially ginned with lint cleaners. Therefore, it would probably qualify for premiums that would not be possible for conventionally ginned cotton. Premiums and discounts were applied based on micronaire, strength, length, and grade.

Irrigation-related costs were estimated from Bryant et al. (2001). All inputs and thus all costs other than irrigation were the same for all treatments; therefore, a partial-budgeting approach was used and only costs related to the different irrigation treatments were considered. For the economic comparisons, the NI treatment represented the situation where water was available at the field but the producer chose not to irrigate. Another possibility would be where a rainfed cotton crop was produced and the water supply was used to irrigate another crop (e.g., rice in an adjacent field). Therefore, an additional treatment (RF) was designated. Agronomically, the NI and RF treatments are the same; however, they are different in the economic analyses because the NI treatment still has associated ownership (fixed) costs. For these analyses, the NI/RF field was assumed to have the same degree of precision grading as the irrigated fields.

Furrow irrigation with disposable irrigation tubing (e.g., Poly-Pipe, Armin Corp., Jersey City, N.J.) was used in the study and the economic analyses, with tubing cost estimated as \$14 ha^{-1}. The annual labor requirement for furrow irrigation was estimated by Bryant et al. (2001) as 0.74 h ha^{-1}. However, that amount includes time spent setting up the field for irrigation and removing the disposable tubing at the end of the season, as well as time spent irrigating. For these analyses, it was assumed that 0.49 h ha^{-1} was required for setup and removal, and 0.06 h ha^{-1} was required for each irrigation, resulting in the same total as Bryant et al. (2001) used for their assumed case of four irrigations.

In addition to the "standard" well (pumping water depth < 37 m) like those at NEREC, Bryant et al. (2001) provided cost information for a "deep" well (37 m < depth < 73 m) and a relift system for a surface water supply. Total costs were calculated for those systems with the other factors held constant to investigate the effect of water source on net revenues. In addition, much Midsouth cropland is rented rather than farmed by the owner; Spurlock and Gillis (2000) reported 71% to 80% rented cropland in the four regions of Mississippi where they surveyed cotton producers. Therefore, it was necessary to consider the impact of rent payments on net returns. While in practice there are a seemingly infinite number of rental arrangements, these analyses assumed a 25% crop-share rent for all treatments, with the landlord providing the well and the farmer paying all costs of production, including the variable costs associated with irrigation.

Bryant et al. (2001) assumed a diesel-powered irrigation pump with fuel costs of \$0.26 L^{-1} (\$1.00 gal^{-1}). While that cost was reasonable for the period of the study (2001 to 2003), fuel costs have been much more volatile in recent years. To investigate the effect of fuel cost, total costs were calculated for fuel costs from \$0.20 to \$1.00 L^{-1} (\$0.76 to \$3.79 gal^{-1}) with all other factors held constant. Similarly, to investigate the effect of lint base price, revenues were calculated for base prices from \$0.50 to \$2.00 kg^{-1} (\$0.23 to \$0.91 lb^{-1}) with all other factors held constant. Finally, since fuel costs have risen considerably, the lint base price calculations were repeated with an assumed doubling of the fuel cost or \$0.53 L^{-1} (\$2.00 gal^{-1}). In each case, revenues were based on 25% crop-share rent with the landlord providing the well and the farmer paying all costs of production, including the variable costs associated with irrigation.

Fisher's least significant difference (LSD) was used to compare treatment means whenever significant ($p \leq 0.05$) treatment effects or interactions were observed.

Results and Discussion

Temperatures during the growing seasons were fairly typical for the area, with little difference among years or between any year and the 30-year means based on heat-unit (growing degree days, 15.6°C base) data for the study period (table 1). Rainfall appeared more variable (table 1). In 2001, only October received more rain than the 30-year mean; however, all but 18 mm of the October total was recorded after the cotton

Table 1. Monthly growing degree days (15.6°C base) and rainfall from weather data collected at NEREC, Keiser, Arkansas.

Month	2001	2002	2003	30-Year Mean[a]
Growing degree days (15.6°C base)				
May	203	133	189	167
June	272	328	245	295
July	384	386	367	355
August	366	352	357	312
September	193	254	169	196
October	67	61	71	70
6-month total	1485	1514	1398	1394
Rainfall (mm)				
May	124	144	289	138
June	59	87	84	91
July	45	51	147	88
August	18	149	17	76
September	49	135	88	101
October	219	120	131	76
6-month total	515	686	757	570

[a] Mean values for the 30 years 1963 through 1992.

was harvested. In 2002, twice the 30-year mean value was recorded in August, typically a peak irrigation month. In 2003, rainfall in May and July both greatly exceeded the 30-year mean; however, 107 mm was recorded on 17 May and again on 29-31 July. Such events are common in the Midsouth, where both too much and too little water can be problems during the same season.

The soils in this study area had poor internal drainage, and large cracks formed as the soil dried, which is expected of a field classified as Sharkey silty clay. However, the surface drainage was quite good. In addition to precision grading, sufficient ditches were available to remove runoff from the field. Many of the fields in the Midsouth with similar soils experience standing water, often for several days, after rainfalls such as those recorded 17 May 2003.

Uniform emergence was observed each season, with approximately 120,000 plants ha^{-1}. Due to the relatively late planting and the corresponding warm temperatures, the crop developed at an accelerated rate in 2002 and 2003. While the COTMAN (Danforth and O'Leary, 1998) target development curve (TDC) indicates first flower at 60 days after planting (DAP), flowers were observed at approximately 52 DAP in 2001 and 2002. Similarly, the COTMAN TDC suggests an effective flowering period, or the time between first flower and NAWF = 5, of 20 days. In 2001, the effective flowering period was 17 days for the WW treatment, but only an average of 9 days for the other treatments, which did not differ significantly (data not included). In 2002, only the WW treatment ever exceeded NAWF = 5, a value associated with physiological cutout (Bourland et al., 1992), suggesting that the plants experienced pre-flower stress. Similarly, in 2003, only the WW and DELAY1 treatments ever exceeded NAWF = 5. However, due largely to the earlier planting and thus cooler early-season temperatures, and the excessive early-season rainfall, crop development was slower in 2003 than in the previous years and flowers were not observed until approximately 80 DAP. Even with adequate surface drainage, the crop growth on the Sharkey soil can still be affected by waterlogged conditions.

Table 2. Estimated net irrigation application amounts in cotton irrigation study at NEREC, Keiser, Arkansas, during 2001 through 2003 growing seasons.

Date	Estimated Net Irrigation Amount (mm)[a]			
	WW	DELAY1	DELAY2	NI
20 July	63	0	0	0
1 August	53	112	0	0
17 August	72	72	182	0
27 August	64	64	64	0
Season total	251	248	246	0
8 July	61	0	0	0
27 July	58	115	0	0
5 August	42	42	155	0
23 August	48	48	48	0
Season total	209	205	204	0
7 July	76	0	0	0
16 July	54	128	0	0
28 July	51	51	177	0
11 August	65	65	65	0
20 August	55	55	55	0
Season total	300	298	297	0

[a] Net irrigation application estimated as the soil water deficit estimated by Arkansas Irrigation Scheduler (Cahoon et al., 1990) on day of irrigation; gross application calculated assuming 67.5% surface irrigation application efficiency.

Irrigation dates and estimated application amounts are included in table 2, based on the assumptions discussed earlier in this article. The Scheduler calculates daily water use for a non-water-stressed crop; however, actual crop evapotranspiration (ET) for the two delayed-irrigation treatments, especially DELAY2, would have been reduced somewhat due to the high SWD experienced. The estimated irrigation amounts were probably higher than the actual amounts applied in the field. However, soil water content was not measured, so a better estimate was not available. Because there were no large rainfalls between the first and third irrigation each year, the estimated total application was approximately the same for each irrigated treatment.

The year with the greatest rainfall (2003) was also the year that had the highest estimated level of applied irrigation water (table 2). The 28 July 2003 irrigation was followed by the 107 mm rainfall of 29-31 July mentioned previously, negating most of the benefit of the irrigation. Similarly, a 44 mm rain followed one day after the final 2002 irrigation on 23 August. Such untimely rainfall is a constant risk in the Midsouth region and underscores the importance of adequate surface drainage.

Gin turnout, the ratio of lint cotton to seedcotton, did not vary significantly among years ($p = 0.69$) or irrigation treatments ($p = 0.79$), and there was no significant year-by-treatment interaction ($p = 0.79$). Therefore, the overall study average value (0.399) was used to calculate lint yield for all plots. Depending on the amount of lint cleaning used in a particular commercial gin, the turnout would probably be slightly lower for commercially ginned cotton. For the three years of the study, average yields decreased with delaying irrigation, and the NI treatment was significantly lower yielding than either the WW or DELAY1 treatment (table 3). There was a consistent trend for lower yield for each delay in the first irrigation each year. In 2003, however, the year with the most rainfall, the differences among all four treatments were not significant. Yields were highest in 2001, the year with the least rainfall.

Table 3. Yield and irrigation water use efficiency from cotton irrigation study at NEREC, Keiser, Arkansas, during 2001 through 2003 growing seasons.

Irrigation Treatment[a]	2001	2002	2003	3-Year Mean[b]
Lint yield (kg/ha)[c]				
WW	975 a	856 a	781 a	870 a
DELAY1	896 ab	606 b	723 a	742 b
DELAY2	879 ab	555 b	698 a	711 bc
NI	722 c	579 b	707 a	670 c
Additional lint yield associated with irrigation (kg ha^{-1})[c]				
WW	252 a	277 a	74 a	201 a
DELAY1	173 a	26 b	16 a	72 b
DELAY2	156 a	–24 b	–9 a	41 b
Estimated irrigation water use efficiency (kg lint ha^{-1} mm^{-1})[c],[d]				
WW	0.68 a	0.89 a	0.17 a	0.58 a
DELAY1	0.47 a	0.09 b	0.04 a	0.20 b
DELAY2	0.46 a	–0.08 b	–0.02 a	0.12 b

[a] WW (well watered) = irrigated at approximately 50 mm soil water deficit (SWD); DELAY1 = missed first irrigation of WW and then irrigated at approximately 50 mm SWD; DELAY2 = missed first two irrigations of WW and then irrigated at approximately 50 mm SWD; and NI = no irrigations.
[b] Means in the same column (3-year) followed by the same letter are not significantly different at the 5% level of significance.
[c] Significant year-by-irrigation-treatment interaction. System means in a column followed by the same letter are not significantly different at the 5% level of significance.
[d] Estimated irrigation water use efficiency (IWUE) = (irrigated treatment lint yield – nonirrigated treatment lint yield) / total estimated gross irrigation.

Yields in this study were lower than those observed by Vories et al. (1991) in a nearby field with similar soils. One possible reason for the lower yields was that two of the three seasons in this study (2002 and 2003) had more rainfall than any of the seasons in the earlier study (1987 to 1989), which likely led to more waterlogging conditions for the plants. Furthermore, the smaller application amounts with sprinkler irrigation (~25 mm) in the earlier study had less of a waterlogging effect than the furrow irrigation employed in this study. Although Cetin and Bilgel (2002) showed higher yields with furrow irrigation than sprinklers in Turkey, Raine and Foley (2002) pointed out that waterlogging associated with irrigation prior to rainfall is much more common with surface irrigation than with sprinklers or drip irrigation. In the earlier NEREC study, there were no differences observed among three treatments based on different allowable SWD; however, the SWDs in the earlier study were all less than the SWD at the first irrigation for either of the delayed-irrigation treatments (DELAY1 and DELAY2) in this study. Yields were also lower than those observed by Pitts et al. (1990) for furrow-irrigated cotton on another NEREC field. Although it is not apparent from the soil descriptions, the surface soil layer in the field where the Pitts et al. (1990) study was conducted is slightly coarser, resulting in improved early-season growth of cotton each season. Vories and Glover (2000) reported their highest yield for a treatment matching the DELAY1 treatment in this study. While they suggested that compensation from later bolls may have affected yields in their study, the late planting in the first two years of this study made any yield compensation unlikely.

The three-year mean additional lint yield associated with irrigation was higher for the WW treatment than for either delayed-irrigation treatment (table 3). However, in two of the three years (2001 and 2003) the differences among the treatments were not significant. The values were lower than observed in the earlier study (Vories et al., 1991, assuming same turnout), in part because the sprinkler irrigation in the earlier study had higher application efficiency than the 67.5% assumed in this study. The IWUE followed the same trends as the additional lint yield. Bordovsky et al. (1992) observed IWUE of 4 kg ha^{-1} mm^{-1} for their most efficient LEPA (low energy, precision application) treatment, much higher than any of the estimated values in this study.

Table 4. HVI fiber quality from cotton irrigation study at NEREC, Keiser, Arkansas, during 2001 through 2003 growing seasons.

Irrigation Treatment[a]	2001	2002	2003	3-Year Mean[b]
Fiber strength (g tex^{-1})				
WW	29.0	26.4	28.8	28.1 a
DELAY1	29.6	27.4	28.2	28.4 a
DELAY2	29.3	26.9	29.2	28.4 a
NI	28.7	26.9	28.8	28.1 a
Fiber upper-half-mean length (mm)[c]				
WW	29.1 a	27.2 ab	27.2 b	27.9 a
DELAY1	28.3 b	27.4 a	27.6 ab	27.8 a
DELAY2	27.9 b	26.9 ab	27.9 a	27.6 a
NI	28.0 b	26.7 b	28.1 a	27.6 a
Fiber micronaire[c]				
WW	5.12 a	5.18 a	5.12 a	5.14 a
DELAY1	4.95 a	4.85 b	5.15 a	4.98 a
DELAY2	5.10 a	4.52 c	4.70 b	4.78 b
NI	4.62 b	4.78 bc	4.32 c	4.64 c

[a] WW (well watered) = irrigated at approximately 50 mm soil water deficit (SWD); DELAY1 = missed first irrigation of WW and then irrigated at approximately 50 mm SWD; DELAY2 = missed first two irrigations of WW and then irrigated at approximately 50 mm SWD; and NI = no irrigations.
[b] Means in the same column (3-year) followed by the same letter are not significantly different at the 5% level of significance.
[c] Significant year-by-irrigation-treatment interaction. System means in a column followed by the same letter are not significantly different at the 5% level of significance.

Fiber strength is primarily a varietal characteristic (Moore, 1994) and was not affected by the irrigation treatments (table 4). Strength varied among years, with values in 2002, the season with the lowest yields, significantly lower than the values in the other years. Fiber length can be affected by limited moisture (Moore, 1994), and differences were observed in this study (table 4); however, no significant differences were observed in the three-year means, and no consistent trends were observed among the years. Micronaire indicates both fineness of the fibers and maturity (Moore, 1994) and can be affected by both cultivar and moisture status. For the three-year mean and each of the years, micronaire for the NI treatment was significantly lower than for the WW treatment; however, the sale price for cotton with micronaire ≥5.0 is discounted (National Cotton Council, 2005, personal communication), and the WW treatment micronaire was >5 in each of the three years of the study (table 4).

Cotton prices are affected by several premiums and discounts, and the averages for the cotton in this study are included in table 5. Based on the price data and lint yields (table 3), gross revenues were calculated for each treatment (table 5). Gross revenues for the WW treatment were numerically greatest each year, although the differences were not significant in 2003. Pitts et al. (1990) reported a greater difference between well watered and nonirrigated treatments

Table 5. Revenue factors from cotton irrigation study at NEREC, Keiser, Arkansas, during 2001 through 2003 growing seasons.

Irrigation Treatment[a]	2001	2002	2003	3-Year Mean
Base Lint Price ($ kg^{-1})				
	1.145	1.146	1.146	1.146
Micronaire premium/discount ($ kg^{-1})				
WW	−0.094	−0.096	−0.088	−0.093
DELAY1	−0.023	0	−0.068	−0.030
DELAY2	−0.094	0	−0.020	−0.038
NI/RF	0	−0.022	0	−0.007
Length and grade premium/discount ($ kg^{-1})				
WW	0.039	−0.037	−0.002	0.000
DELAY1	0.047	−0.057	0.022	0.004
DELAY2	0.042	−0.061	0.044	0.008
NI/RF	0.044	−0.073	0.010	−0.006
Strength premium/discount ($ kg^{-1})				
WW	0.002	0	0.002	0.001
DELAY1	0.003	0	0	0.001
DELAY2	0.005	0	0.002	0.002
NI/RF	0.002	0	0.002	0.001
Total premium/discount ($ kg^{-1})				
WW	−0.053	−0.133	−0.088	−0.091
DELAY1	0.027	−0.057	−0.046	−0.025
DELAY2	−0.047	−0.061	0.026	−0.027
NI/RF	0.045	−0.095	0.012	−0.012
Adjusted lint price ($ kg^{-1})				
WW	1.092	1.013	1.058	1.054
DELAY1	1.172	1.089	1.100	1.120
DELAY2	1.098	1.086	1.172	1.119
NI/RF	1.190	1.051	1.159	1.133
Gross revenue ($ ha^{-1})[b]				
WW	1064 a	866 a	825 a	919 a
DELAY1	1049 a	660 b	790 a	833 b
DELAY2	964 ab	603 b	820 a	796 bc
NI/RF	859 b	607 b	820 a	762 c

[a] WW (well watered) = irrigated at approximately 50 mm soil water deficit (SWD); DELAY1 = missed first irrigation of WW and then irrigated at approximately 50 mm SWD; DELAY2 = missed first two irrigations of WW and then irrigated at approximately 50 mm SWD; and NI/RF = no irrigations.

[b] Significant year-by-system interaction. System means in a column followed by the same letter are not significantly different at the 5% level of significance.

($420 ha^{-1}), even with a lower assumed gin turnout; however, the yield differences between treatments were larger.

The estimated costs associated with the irrigation treatments are included in table 6, based on Bryant et al. (2001). Since the estimated irrigation amounts did not vary greatly, the estimated costs did not vary greatly for a given water source. When irrigation costs were considered, the estimated net revenues associated with the WW treatment were not always numerically greatest (table 7). In fact, in 2003, the estimated net revenues for the RF treatment (i.e., no fixed costs) were significantly higher than those for any irrigated treatment. Three-year-mean estimated net revenue for the WW and RF treatments were not significantly different, while the DELAY2 treatment was significantly lower than either. Pitts et al. (1990) reported a greater difference between well watered and nonirrigated (comparable to the RF treatment in this study) treatments ($239 ha^{-1}) than the $53 ha^{-1} difference observed in this study, although different assumptions were used in the earlier study.

Table 6. Total estimated irrigation costs for different water sources[a] from cotton irrigation study at NEREC, Keiser, Arkansas, during 2001 through 2003 growing seasons.

Irrigation Treatment[b]	2001	2002	2003	3-Year Mean
Standard irrigation well ($ ha^{-1})				
WW	103	96	112	104
DELAY1	102	95	112	103
DELAY2	102	94	111	102
NI	40	40	40	40
RF	0	0	0	0
Deep irrigation well ($ ha^{-1})				
WW	145	134	158	145
DELAY1	143	132	157	144
DELAY2	142	131	156	143
NI	60	60	60	60
RF	0	0	0	0
Stationary relift system ($ ha^{-1})				
WW	85	81	91	86
DELAY1	85	80	90	85
DELAY2	84	80	90	84
NI	41	41	41	41
RF	0	0	0	0

[a] Standard well depth < 37m; 37m < deep well depth < 73m; and stationary relift with 6 m maximum vertical pipe (Bryant et al., 2001).

[b] WW (well watered) = irrigated at approximately 50 mm soil water deficit (SWD); DELAY1 = missed first irrigation of WW and then irrigated at approximately 50 mm SWD; DELAY2 = missed first two irrigations of WW and then irrigated at approximately 50 mm SWD; NI = no irrigations; and RF (rainfed) = no irrigations and water supply used to irrigate another crop.

For the case of a deep well water source, which Bryant et al. (2001) defined as between 37 m and 73 m, there was a higher energy requirement for pumping and therefore higher irrigation costs. The three-year-mean estimated net revenues for both delayed-irrigation treatments were significantly lower than for the WW or RF treatments, which were not significantly different from each other. However, for a surface water source, with lower energy requirements and therefore lower irrigation costs, three-year-mean estimated net revenues for all other treatments were significantly lower than the WW treatment and were not significantly different from each other. Similarly, for the case of a 25% crop-share rent with the landlord supplying the standard well, three-year-mean estimated net revenues for all other treatments were significantly lower than for the WW treatment and were not significantly different from each other.

A sensitivity analysis was conducted to determine the impact of variations in lint and diesel prices on estimated net revenues. Because much of the Midsouth farmland is not farmed by the owner, the analysis assumed the case of a standard well with all ownership costs for the well paid by the landlord, and 25% crop-share rent. Only three-year-mean estimated net revenues were considered and not year-to-year variability. As previously stated, the preceding analyses were based on an assumed diesel cost of $0.26 L^{-1} ($1.00 gal^{-1}). When all other factors were held constant and the lint prices from the previous analyses were used, the WW treatment had higher estimated net revenues than the NI/RF (same treatment as far as the producer is concerned when the landlord pays ownership costs) for diesel cost < $0.65 L^{-1} ($2.47 gal^{-1}) (fig. 1). When diesel cost > $0.65 L^{-1}, the costs associated with irrigation were not offset by higher gross rev–

Table 7. Estimated net revenues for different water sources[a] and crop-share rent from cotton irrigation study at NEREC, Keiser, Arkansas, during 2001 through 2003 growing seasons.

Irrigation Treatment[b]	2001	2002	2003	3-Year Mean[c]
Standard irrigation well ($ ha^{-1})[d]				
WW	961 a	770 a	713 b	815 a
DELAY1	947 a	565 b	678 b	730 bc
DELAY2	862 ab	509 b	709 b	693 c
NI	819 b	567 b	780 ab	722 bc
RF	859 ab	607 b	820 a	762 ab
Deep irrigation well ($ ha^{-1})[d]				
WW	920 a	733 a	667 bc	773 a
DELAY1	906 a	528 bc	633 c	689 c
DELAY2	822 ab	472 c	664 bc	652 c
NI	799 b	547 bc	760 ab	702 bc
RF	859 ab	607 b	820 a	762 ab
Stationary relift system ($ ha^{-1})[d]				
WW	979 a	785 a	734 a	833 a
DELAY1	965 ab	580 b	699 b	748 b
DELAY2	880 abc	523 b	730 ab	711 b
NI	818 c	566 b	779 ab	721 b
RF	859 bc	607 b	820 a	762 b
Standard well provided by landlord and 25% crop-share rent ($ ha^{-1})[d]				
WW	735 a	594 a	547 ab	625 a
DELAY1	725 ab	440 b	521 b	562 b
DELAY2	662 ab	398 b	544 ab	535 b
NI/RF	644 b	455 b	615 a	572 b

[a] Standard well depth < 37m; 37m < deep well depth < 73m; and stationary relift with 6 m maximum vertical pipe (Bryant et al., 2001).

[b] WW (well watered) = irrigated at approximately 50 mm soil water deficit (SWD); DELAY1 = missed first irrigation of WW and then irrigated at approximately 50 mm SWD; DELAY2 = missed first two irrigations of WW and then irrigated at approximately 50 mm SWD; NI = no irrigations; and RF (rainfed) = no irrigations and water supply used to irrigate another crop.

[c] Means in the same column (3-year) followed by the same letter are not significantly different at the 5% level of significance.

[d] Significant year-by-system interaction. System means in a column followed by the same letter are not significantly different at the 5% level of significance.

enues. The DELAY1 treatment, a fairly common situation on Midsouth cotton farms, was only more profitable than NI/RF when diesel cost < $0.19 L^{-1} ($0.74 gal^{-1}).

In addressing lint price effects, only the base price was varied and the same premiums and discounts were applied as in the previous analyses. When all other factors were held constant with an assumed diesel cost of 0.26 L^{-1} ($1.00 gal^{-1}), the WW treatment had higher estimated net revenues than NI/RF for lint base price > $0.79 kg^{-1} ($0.36 lb^{-1}) (fig. 2). The DELAY1 treatment was only more profitable than NI/RF when lint base price > $1.32 kg^{-1} ($0.60 lb^{-1}). When diesel cost doubled to 0.53 L^{-1} ($2.00 gal^{-1}), the WW treatment had higher estimated net revenues than NI/RF for lint base price > $1.03 kg^{-1} ($0.47 lb^{-1}) (fig. 3). The DELAY1 treatment was only more profitable than NI/RF when lint base price > $1.99 kg^{-1} ($0.90 lb^{-1}). Of course, with all the sensitivity analyses, the values would change if a different land rent was assumed.

While there are many obstacles to profitable cotton production on clay soil, this study underscores the importance of proper irrigation management. Delaying the initial furrow irrigation is a common practice in Midsouth cotton production, especially for clay soils where a longer time is required for the soil to dry enough to be trafficable. In all the scenarios investigated, the delayed-irrigation treatments (DELAY1 and DELAY2) had significantly lower estimated net revenues than the WW treatment and were not significantly different from the NI treatment. These data also suggested that when the water supply could be better used elsewhere, the estimated net revenue for a rainfed cotton crop (RF treatment)

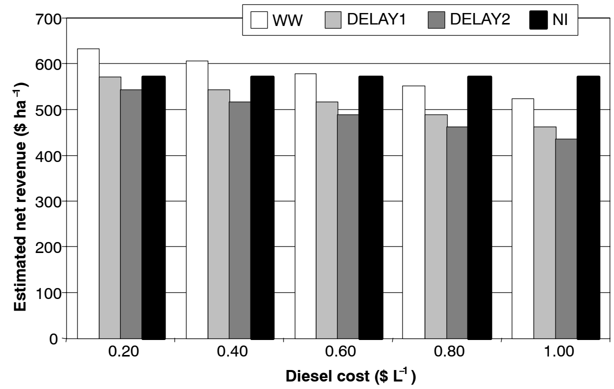

Figure 1. Three-year-mean effect of diesel cost on estimated net revenue for a standard well provided by the landlord and 25% crop-share rent from cotton irrigation study at NEREC, Keiser, Arkansas, during 2001 through 2003 growing seasons.

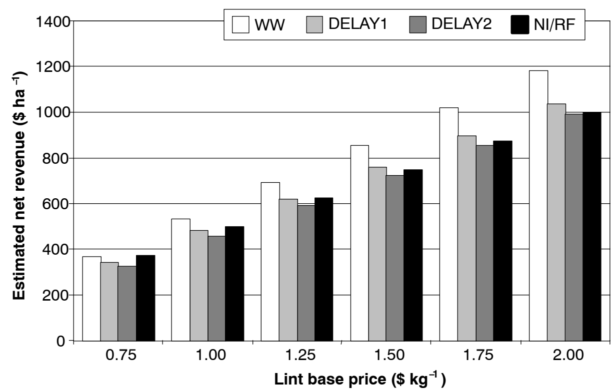

Figure 2. Three-year-mean effect of lint base price on estimated net revenue for a standard well provided by the landlord, 25% crop-share rent and diesel costing $0.26 L^{-1} ($1.00 gal^{-1}) from cotton irrigation study at NEREC, Keiser, Arkansas, during 2001 through 2003 growing seasons.

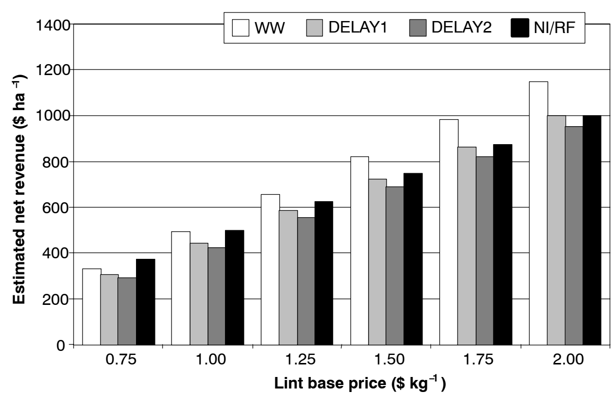

Figure 3. Three-year-mean effect of lint base price on estimated net revenue for a standard well provided by the landlord, 25% crop-share rent and diesel costing $0.53 L^{-1} ($2.00 gal^{-1}) from cotton irrigation study at NEREC, Keiser, Arkansas, during 2001 through 2003 growing seasons.

was not significantly different from the WW treatment for wells more than 73 m deep. However, not irrigating when the water was not used elsewhere (NI treatment) still resulted in ownership costs, making the estimated net revenue significantly less than for the WW treatment.

Conclusions

Midsouth rainfall is quite variable, which exacerbates the problems with crop production on clay soils. In this study, the year with the greatest rainfall (2003) was also the year that had the highest estimated level of applied irrigation water. Rainfall soon after a surface irrigation is a constant risk in the Midsouth region and underscores the importance of adequate surface drainage. Three-year-average yields decreased with delaying irrigation, and the NI treatment was significantly lower yielding than either the WW or the DELAY1 treatment. For the three years, there was a consistent trend for lower yield for each delay in the first irrigation; however, in 2003, the differences among all four treatments were not significant. Yields were highest in 2001, the year with the least rainfall. The three-year-mean irrigation water use efficiency was higher for the WW treatment than for either delayed-irrigation treatment; however, in two of the three years (2001 and 2003) the differences among the treatments were not significant. Fiber strength was not affected by the irrigation treatments, and no consistent trends were observed among the years for fiber length. Micronaire for the NI treatment was significantly lower than for the WW treatment each year; however, micronaire was >5 each year for the WW treatment, a value usually associated with price discounts.

Gross revenues for the WW treatment were numerically greatest each year, although the differences were not significant in 2003. However, when the estimated costs of irrigation were included, estimated net revenues for the WW treatment were not always numerically greatest. In fact, in 2003, estimated net revenues for the RF treatment (i.e., no fixed costs) were significantly higher than those for any irrigated treatment. Three-year-mean estimated net revenue for the WW and RF treatments were not significantly different, while those for the DELAY2 treatment were significantly lower than either. When different scenarios were investigated (different water sources, rented farmland), the delayed-irrigation treatments (DELAY1 and DELAY2) had significantly lower estimated net revenues than the WW treatment and were not significantly different from the NI treatment. When all other factors were held constant for the rented farmland situation, the WW treatment had higher estimated net revenues than the NI/RF treatments (same treatment as far as the producer is concerned when the landlord pays ownership costs) for diesel cost < \$0.65 L^{-1} (\$2.47 gal^{-1}). The DELAY1 treatment, a fairly common situation on Midsouth cotton farms, was only more profitable than the NI/RF treatments when diesel cost < \$0.19 L^{-1} (\$0.74 gal^{-1}). Similarly, when diesel cost \$0.26 L^{-1} (\$1.00 gal^{-1}), the WW treatment had higher estimated net revenues than the NI/RF treatments for lint base price > \$0.79 kg^{-1} (\$0.36 lb^{-1}), and the DELAY1 treatment was only more profitable than the NI/RF treatments when lint base price > \$1.32 kg^{-1} (\$0.60 lb^{-1}). When diesel cost doubled to \$0.53 L^{-1} (\$2.00 gal^{-1}), the WW treatment had higher estimated net revenues than the NI/RF treatments for lint base price > \$1.03 kg^{-1} (\$0.47 lb^{-1}), and the DELAY1 treatment was only more profitable than the NI/RF treatments when lint base price > \$1.99 kg^{-1} (\$0.90 lb^{-1}).

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