COTTON RESPONSE TO IRRIGATION TIMING AND USE OF ENHANCED EFFICIENCY NITROGEN FERTILIZER AND BIOSOLIDS

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Abstract

In a three year field trial at the Judd Hill Foundation in northeast Arkansas, we evaluated cotton response to four N fertilizer treatments,100 lb N applied as either: 1) urea, 2) enhanced efficiency N (trade name ESN), 3) urea + 300 lb/A biosolids (trade name Top Choice) or 4) unfertilized check (0 N) grown using three furrow irrigation regimens: 1) Late Start (weekly irrigation started at first flowers, 2) Early Start (irrigation started at early squaring) and 3) Rainfed (no irrigation). We documented plant response to water and nutrients including pace of nodal development, square and boll retention using weekly in-season plant monitoring with the COTMAN system. Fertilized cotton yielded similar amounts regardless of urea formulation or addition of biosolids; plants in the unfertilized check produced the lowest yields. In the hot, dry summers of 2010 through 2012, fertilized cotton receiving irrigation produced significantly higher lint yields than rainfed. An early start time for irrigation produced highest yields. If irrigation start time was delayed, fertilized plants developed fewer main stem fruiting branches by first flowers, shed more small bolls in the first two weeks of flowering, reached physiological cutout (NAWF=5) later, and produced 16% lower lint yields compared to cotton grown with early start irrigation.

Introduction

Timing irrigation initiation in cotton to avoid pre-flower water deficit stress has been shown to improve earliness and increase cotton yields in Arkansas (Teague and Danforth, 2009, 2010; Teague, 2011). Cotton roots take up N fertilizer only if is dissolved in water, so if soil water is limited during squaring, plants will suffer from both water and N deficiency. Irrigation timing will impact availability of N for crop development and formulations of N fertilizer that are slow release may impact crop growth and compensation capacity to recover from pre-flower stress. In this research project, we compared cotton plant response to different N fertilizer types in cotton grown with no irrigation, early start irrigation, or delayed start irrigation. We evaluated crop fruiting development progress and compensation capacity following stress or early irrigation and examined N fertilizer effects on crop maturity and lint quality.

Materials and Methods

The experiment, conducted at the Judd Hill Research Farm near Trumann, AR, was designed as a 3X4 factorial experiment with irrigation timing (3 factors) and N fertilizer (4 factors) arranged in a split plot with irrigation considered main plots. Early start irrigation was initiated either just prior to or during the 1st week of squaring or was delayed 1.5 to 3 additional weeks until the time of first flowers (delayed start) (Table 1). A non-irrigated control (rainfed) was included. Fertilizer was applied prior to planting at 100 lb N/acre either as urea, urea + 300 lb/ac biosolids (trade name Top Choice Organic),or polymer coated urea (trade name ESN). Top Choice is a 4-3-0 biosolids soil amendment available from Top Choice Organic, Poinsett Fertilizer, Trumann, AR. ESN is a controlled release fertilizer from Agrium, Inc. An unfertilized check (0 N) also was included.

Production practices were similar across all treatments in-season including insect and weed control, plant growth regulator application and defoliation; only irrigation start timing and N fertilizer inputs were varied for the study. Weekly insect pest scouting in each plot confirmed efficacy of insect pest control tactics and ensured no confounding effects across fertilizer or irrigation treatments from insect induced feeding injury. Plots were maintained in the same location each year. Fertilizers were broadcast by hand and incorporated using disk bedders. The following day, tops of beds were flattened with a Do-All, and plots were seeded. Cruiser treated Stoneville 4288 B2RF was planted in the Dundee silt loam soil at 3 to 4 seeds/ft. in 38 inch raised beds on 7 May 2010; DPL 0912 B2R2 was planted11 May 2011, and 2 May 2012.

Irrigation was applied using polyethylene irrigation tubing (poly pipe) for furrow irrigation. Water was delivered to every row in appropriate main plots. We used simple cues for timing the early and late irrigation start times. After crop plants reached 4 true leaf stage, early start irrigation was initiated if there was one full week without rainfall.

The late start timing was typical furrow irrigation start time (=lay by) for cotton growers in Arkansas and generally occurs at the time of first flowers. Our late start date each year corresponded to the furrow irrigation start date of the commercial producers on the surrounding Judd Hill Foundation farm. After initiation, irrigation frequency (approximately weekly) and irrigation termination timing followed standard practices in the region.

Table 1. Irrigation timing dates for early start and delayed start irrigation timing for 2010, 2011 and 2011 Judd Hill irrigation timing * N source field trial.

Year	Irrigation start time	Date of irrigation	Irrigation timing (days after planting)
2010	Early	12, 18, 24 June, 1, 8, 23, July, 3, 11 August	36, 42, 48, 55, 62, 77, 88, 96
	Delayed	24 June, 1, 8, 23, July, 3, 11 August	48, 55, 62, 77, 88, 96
2011	Early	3, 10, 16, 24 June, 1, 8, 13, 20, 27 July, 3, 11 Aug	23, 30, 36, 44
	Delayed	1, 8, 13, 20, 27 July, 3, 11 Aug	51, 58, 63, 70, 77, 84, 92, 100
2012	Early	23 May, 13, 19, 28 June, 3, 13, 20 27 July, 2 August	21, 30,42, 48,57, 62, 72, 79, 86, 92
	Delayed	19, 28 June, 3, 13, 20 27 July, 2 August	48,57, 62, 72, 79, 86, 92

The COTMAN crop monitoring system (Oosterhuis and Bourland 2008) was used to document differences in crop development among irrigation and fertilizer treatments from squaring through flowering, boll development, and physiological cutout. Following standard COTMAN Squaremap sampling protocols, we examined two sets of five consecutive plants in the center rows of each plot weekly. We measured plant height (soil to apex), and recorded presence or absence of first position squares and bolls on main stem squaring nodes (sympodia that have not yet produced a flower) and boll nodes (sympodia that have produced flowers). The progress of nodal development for each treatment was compared to the standard COTMAN target development curve. Squaremap sampling of consecutive plants was continued until ca. 80 days after planting (DAP) to document retention and to measure treatment effects on physiological shed of small bolls (ca. <9 days old). Nodes above white flower (NAWF) counts provide a rapid means of counting squaring nodes per plant in mid-season, and we took weekly counts of NAWF for 10 plants in the center rows of each plot. The Bollman component of the COTMAN software was used to calculate days to physiological cutout (NAWF=5).

End-of-season season final plant mapping was performed using the COTMAP procedure (Bourland and Watson 1990). Ten plants in one designated harvest row per plot were examined for node number of first (lowest) sympodial branch on the main axis, number of monopodia, and number of bolls on sympodia arising from monopodia. Bolls located on main stem sympodia (1st and 2nd position) were recorded, as well as bolls located on the outer positions on sympodial nodes (>2nd position). The highest sympodium with 2 nodal positions and number of bolls on sympodia located on secondary axillary positions also were noted. Plant height was measured as distance from soil to apex.

Applications of defoliants and boll openers were made 27 Aug and 3 Sept 2010 (112 and 119 DAP), 8 and 16 Sept 2011 (120 and 128 DAP), 4 and 10 Sept 2012 (125 & 131 DAP) (2444, 2735, and 2156 DD60s after planting for 2010, 2011, 2012, respectively). Following defoliation, 50 handpicked boll samples were collected, ginned, and submitted for HVI fiber quality determinations. Yields were determined using a 2-row research cotton picker, which was used to harvest two center rows per plot. Harvest was completed 17 September 2010 (133 DAP), 28 Sept 2011 (140 DAP), 24 Sept 2012 (145 DAP). In 2011, we performed a second picking on 11 October to evaluate contribution of late season upper canopy bolls to total yield. Data were analyzed using ANOVA with mean separation using protected LSD.

Results

Summer weather generally was hot and dry during 2010, 2011, and 2012 crop seasons. Heat unit and rainfall summaries for June through September for the three study years indicated warmer and drier conditions compared with 50-year averages from northeast Arkansas (Table 2). With relatively low rainfall during the critical periods from first squares to first flowers, weather conditions were ideal for comparing plant response to both irrigation timing and N fertilizer. In both 2010 and 2012, there was no measurable rainfall in June at the Judd Hill research site (Table 2). In the 2011 season, 1.19 inches of rainfall were recorded on 16 June, 36 DAP. By this date, plants had produced an average 2 to 3 squaring nodes per plant, and early start treatments had received 2 early irrigations.

Irrigation start times for the three seasons were 500, 310, and 314 DD60s after planting for early start and 923, 993 and 777 DD60s after planting for late start for 2010, 2011, 2012, respectively (Table 3).

Table 2. Average monthly heat unit (DD60s) and precipitation accumulation, 1960-2007 for Northeast Arkansas[1] compared to 2010, 2011, 2012 on-farm measurements at Judd Hill.

Month	Heat Units (DD60s)				Rain (inches)			
	Average	2010	2011	2012	Average	2010	2011	2012
June	532	732	758	492	3.89	0.0	1.8	0.0
July	644	721	936	574	3.67	7.0	0.8	1.2
August	583	730	722	747	2.85	0.3	0.1	1.6
September	363	454	312	601	3.73	0.8	1.5	5.21

[1]Source: NOAA National Climatic Data Center, daily surface data for Keiser, AR.
[2]Heat unit calculations were based on average daily temperature calculated using high and low temperatures (Daily Heat Units= ((High+Low)/2)-60)

COTMAN growth curves from each season showed similar trends in crop response to N fertilizer treatments and irrigation regime; representative curves from 2011 season are shown (Figure 1). For rainfed plants, reduced soil moisture slowed plant growth and likely reduced availability of soil N from fertilizer applications. Growth curves show that the pace of mainstem nodal development was similar for fertilized and unfertilized plants. Unfertilized plants in irrigated treatments showed a similar pattern of nodal development. When compared to the standard target curve, these plants produced fewer mainstem nodes by first flowers, and after flowers, and they reached physiological cutout earlier than expected. The effective flowering period for a normal cotton crop is 3 to 4 weeks, but for these plants, environmental stress from low soil moisture and/or limited N availability resulted in limited flowering and premature cutout.

For fertilized, irrigated cotton in 2011, differences in nodal development among treatments was apparent by 41 DAP; early irrigated plants had produced one additional squaring node per plant compared to either late start or rainfed plants (5.8 squaring nodes compared to 4.7 and 4.4 squaring nodes, respectively) ($P=0.05$; $LSD_{05}=1.0$). These differences among irrigation treatments continued until first flowers. Overall, we observed no differences in preflower nodal development noted among the three fertilizer sources.

First position square retention rates among all treatments in all years was maintained above 90% up to first flowers. Following anthesis, the pace for nodal development of plants with such high retention rates should decline during the 3 next weeks from 9.25 to 5 squaring nodes. The COTMAN target date for 5 squaring nodes is 80 DAP. In 2011, where irrigation start time was delayed and plants were fertilized with urea, squaring nodes were > 5 at 80 DAP, an indication the crop maturity was delayed with this treatment combination (Figure 1).

Table 3. Dates of planting, heat units (HU) from planting, and irrigation timing dates for early start and delayed start irrigation timing for 2010, 2011 and 2011 Judd Hill irrigation timing * N source field trial.

Year	Date of planting	Days to first flowers	HU to first flowers (DD60s)	Irrigation start time	Days to Irrigation Start	HU to irrigation start (DD60s)
2010	7 May	52	1032	Early	36	500
				Delayed	48	923
2011	11 May	55	1109	Early	23	310
				Delayed	51	993
2012	2 May	61	995	Early	21	314
				Delayed	48	777

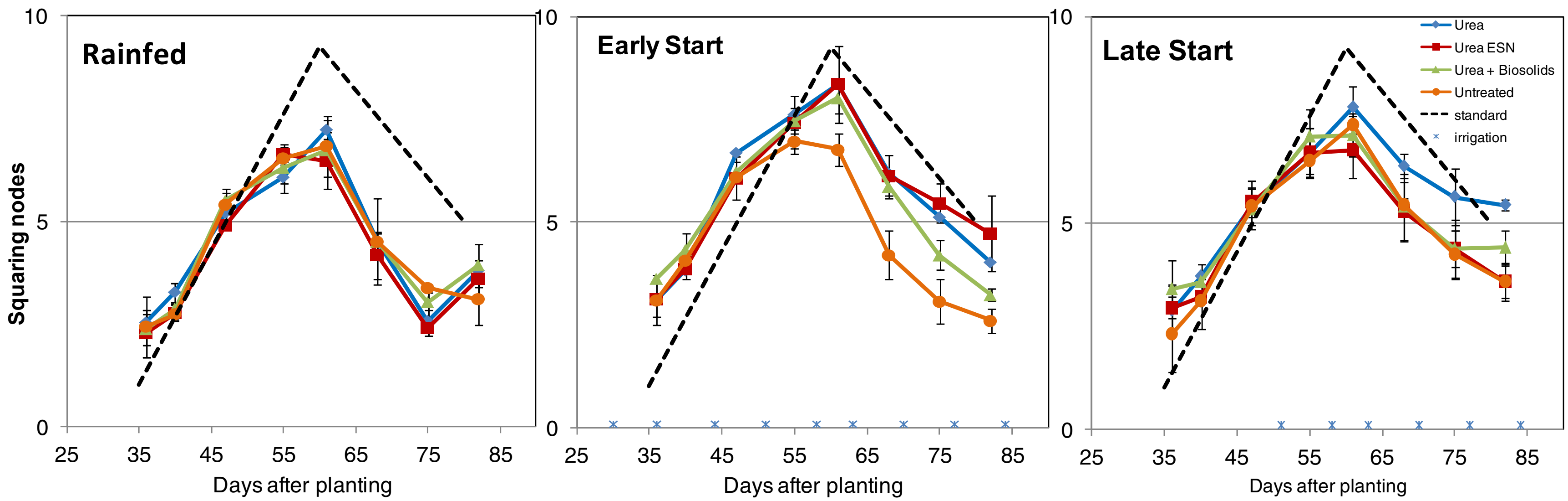

Figure 1. COTMAN growth curves for 2011 cotton fertilized with either Urea, Urea ESN, Urea + Biosolids or untreated and irrigated with an early, late start or rainfed.

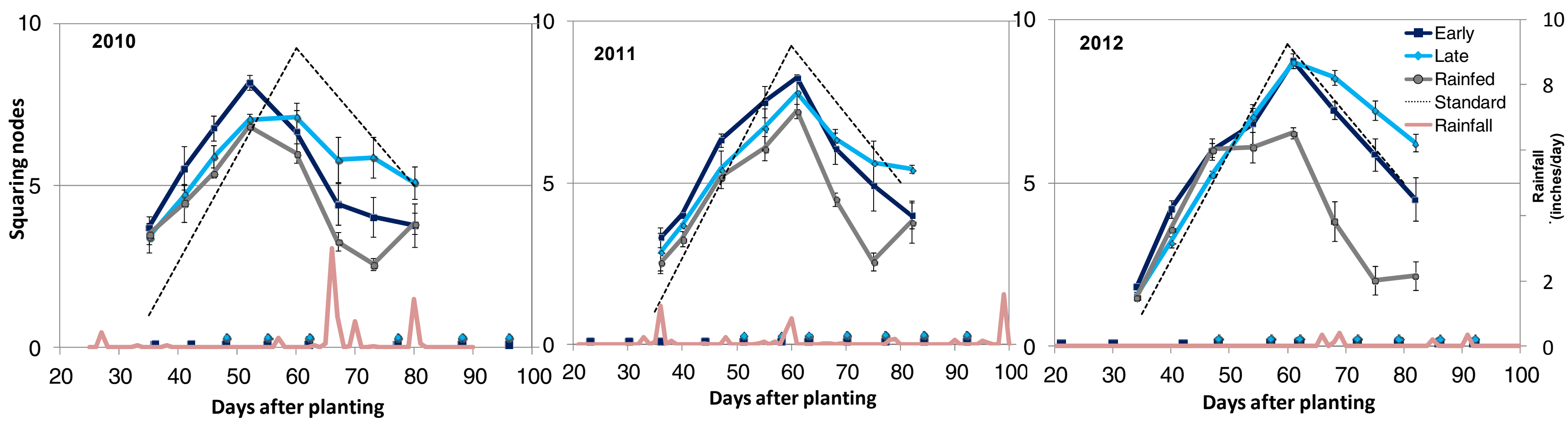

Figure 2. COTMAN growth curves for urea fertilized cotton showing irrigation timing effects for 2010, 2011 and 2012. Irrigation dates and daily rainfall are shown on the x-axis.

If irrigation main effects were examined among only urea fertilized plants, growth curves all three years clearly show how preflower water deficits impacted nodal development during the critical period from first squares through anthesis and how that preflower stress affected flowering dynamics and crop maturity (Figure 2). We recorded first flowers in COTMAN monitoring across *all* plots by 52, 55 and 61 DAP in 2010, 2011 and 2012, respectively. We did observe flowers 1 to 3 days earlier in the warmer, rainfed main plots. For 2010 and 2011 in the first week of flowers, the mean number of squaring nodes was less than the expected 9.25 target value for COTMAN in all treatments, and there were significant differences in nodal production among irrigation treatments. Early irrigated fertilized plants produced more main stem squaring nodes by first flowers (8.3 nodes) compared to fertilized plants in delayed irrigation or rainfed treatments (7.3 and 6.1 squaring nodes, respectively) ($P=0.007$; $LSD_{0.05}=0.78$). Urea fertilized irrigated plants in 2012 closely followed the COTMAN standard curve. No differences in preflower nodal development between early and late start irrigation were observed. June 2012 temperatures were cooler than for June 2010 and 2011, and first flowers were noted 5 to 6 days later in 2012 (61 compared to 52 and 55 DAP) (Table 3). Although irrigation start timing was similar in days, because of the cooler temperatures, the irrigation start time occurred one week *prior* to first flowers (777 DD60s after planting in 2012 compared to >900 DD60s after planting in 2010 and 2011). With the "extra" week, there was increased time for nodal development in 2012 compared to other years.

For all three seasons, irrigation timing significantly affected crop maturity -- days from planting to NAWF=5 ($P=0.04$; $LSD_{05}=12$). Cotton plants respond to environmental stress and boll load by "cutting out". Pre-mature cutout was observed for rainfed cotton with mean days to NAWF=5 ranging from 62 to 66 days after planting (Figure 3). In all three years for fertilized cotton, late irrigation initiation resulted in delayed maturity compared to an early start. One likely factor leading to crop delay was reduced boll load resulting from preflower stress followed by late irrigation. First position small boll abscission (<9 days old) in 2010 and 2011 increased around 70 DAP (Figure 4), and waiting to start irrigation until first flowers resulted in highest % boll shed. No differences among treatments were observed in small boll shed in 2012. Physiological boll shed during the first 2 to 3 weeks of flowering often is accompanied by changes in slope of COTMAN growth curve after flowers. A reduced slope is interpreted as an indication of lower metabolic stress from boll loading and represents a crop maturity delay (Bourland et al. 2008). The 2012 growth curves for late start irrigation followed this pattern (Figure 2).

Small boll shed, documented in-season using COTMAN in 2010 and 2011, also was evident in results from end-of-season plant mapping with COTMAP (Table 4). Plants retained fewer first position bolls if irrigation was delayed. Plants with late start irrigation produced more sympodia per plant and were taller than either rainfed plants or plants receiving early irrigation. Rainfed plants were short with fewest nodes and bolls.

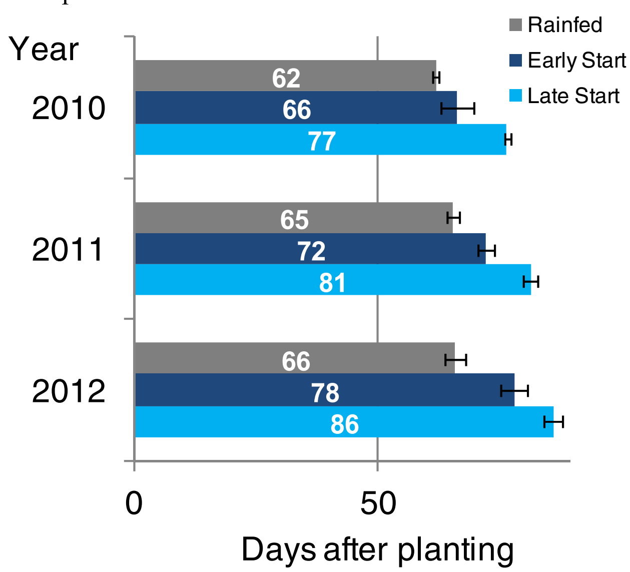

Figure 3. Mean (±SEM) no. days to physiological cutout based on counts of nodes above white flower (NAWF) for urea fertilized plants for rainfed, early start and late start irrigation main plot effects for the three years ($P=0.04$; $LSD_{05}=12$).

Table 5. Results from end-of-season plant mapping for irrigation timing main plot effects for fertilized plants (no unfertilized checks were included) - Judd Hill 2010, 2011, 2012[1].

Category	2010					2011					2012				
	Early	**Late**	**Rain**	***P>F***	***LSD_{05}***	**Early**	**Late**	**Rain**	***P>F***	***LSD_{05}***	**Early**	**Late**	**Rain**	***P>F***	***LSD_{05}***
1st Sympodial Node	6.4	6.3	6.2	*0.18*		6.8	6.5	6.9	*0.39*		6.1	5.9	6.0	*0.59*	
No. of Sympodia	13.9	15.8	12.3	*0.03*	*2.3*	14.9	18.3	12.2	*<.01*	*1.6*	14.7	15.7	11.2	*<.01*	*1.0*
No. of Monopodia	2.0	1.3	1.2	*0.01*	*0.4*	2.3	2.1	2.2	*0.74*		1.7	1.3	2.0	*0.01*	*0.3*
Highest Sympodia with 2 nodes	10.3	11.9	8.7	*0.02*	*0.2*	10.7	13.5	7.9	*0.002*	*0.9*	11.3	12.1	8.1	*<.01*	*0.8*
Plant Height (inches)	35.7	35.7	24.0	*0.02*	*7.6*	40.1	40.0	23.3	*<.01*	*1.1*	37.7	34.5	19.8	*<.01*	*1.9*
No. of Effective Sympodia	7.4	8.3	5.5	*0.02*	*1.5*	8.6	8.8	3.7	*<.01*	*1.6*	9.5	10.0	4.3	*<.01*	*1.0*
No. of Sympodia with 1st Position Bolls	4.8	3.9	3.5	*0.06*	*1.1*	5.0	3.6	2.9	*<.01*	*0.8*	5.7	5.0	3.4	*<.01*	*0.7*
No. of Sympodia with 2nd Position.Bolls	1.1	1.1	0.3	*0.01*	*0.5*	1.0	1.3	0.2	*0.01*	*0.5*	1.2	1.2	0.1	*0.03*	*0.8*
No. of Sympodia with 1st & 2nd Position Bolls	0.4	0.4	0.3	*0.6*		0.6	0.7	0.2	*0.01*	*0.2*	0.8	1.2	0.3	*0.18*	*1.0*
Total Bolls/Plant	7.1	6.7	4.6	*<.01*	*0.9*	7.7	6.8	4.1	*<.01*	*0.8*	9.2	9.4	4.5	*0.03*	*3.7*
% Total Bolls in 1st Position	72.6	63.6	84.2	*0.01*	*7.9*	73.1	62.6	79.7	*0.01*	*8.7*	71.5	67.7	84.8	*0.09*	*16.2*
% Total Bolls in 2nd Position	20.5	21.2	10.9	*0.03*	*7.2*	19.7	28.0	8.8	*0.01*	*7.4*	19.9	24.0	10.0	*0.04*	*9.8*
% Total Bolls in Outer Position	1.7	10.9	1.3	*0.02*	*6.0*	0.3	0.0	0.0	*0.44*	*0.6*	2.1	4.0	0.0	*0.01*	*1.9*
% Total Bolls on Monopodia	4.6	3.8	3.6	*0.87*		7.0	9.0	11.5	*0.16*		5.2	4.1	5.2	*0.85*	
% Total Bolls on Extra – Axillary	0.6	0.5	0.0	*0.23*		0.0	0.4	0.0	*0.16*		1.3	0.1	0.0	*0.05*	*1.0*
% Boll Retention - 1st Position	37.4	27.0	31.0	*0.02*	*6.2*	37.8	23.5	26.0	*<.01*	*4.3*	43.8	39.4	33.2	*0.09*	*7.1*
% Boll Retention - 2nd Position	14.4	12.3	6.0	*0.03*	*5.6*	14.3	14.3	5.2	*0.01*	*4.6*	16.4	18.9	5.5	*0.33*	*13.1*
% Early Boll Retention	45.2	35.0	35.9	*0.02*	*6.5*	47.3	36.9	34.8	*0.01*	*6.6*	47.1	49.1	39.7	*<.01*	*16.0*
Total Nodes/Plant	19.3	21.1	17.5	*0.02*	*2.2*	20.7	23.9	18.1	*0.01*	*1.4*	19.7	20.6	16.3	*<.01*	*1.0*
Internode Length (inches)	1.9	1.7	1.4	*0.01*	*0.2*	1.9	1.7	1.3	*0.01*	*6.6*	1.9	1.7	1.2	*<.01*	*0.1*

[1] means of 10 consecutive plants per plot using COTMAP sampling protocols.

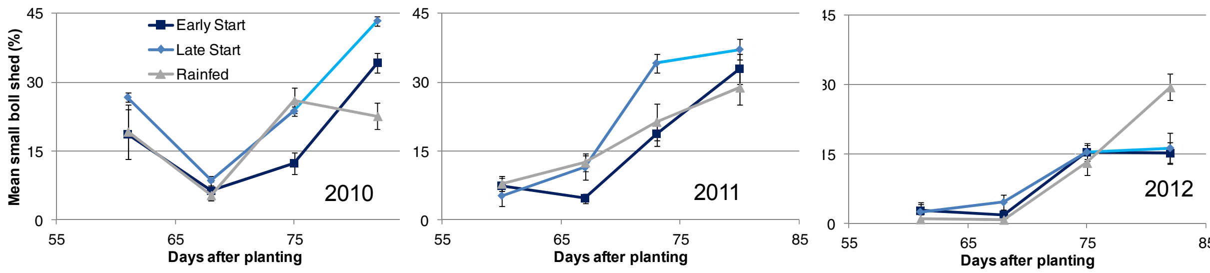

Figure 4. Mean (±SEM) small boll shed from fertilized plants (urea, urea+biosolids, ESN) among the three irrigation timing treatments in 2011; small boll counts were based on retention of the three uppermost first position bolls on two sets of five consecutive plants sampled using COTMAN Squaremap protocol.

For N fertilizer effects, end of season COTMAP results showed no plant structural differences among fertilizer sources; however, plants in the unfertilized check were shorter, produced fewer sympodia and monopodia, and had a lower value for highest sympodia with 2 positions. Fewest total bolls per plant were noted in the untreated check; this treatment also had significantly fewer effective sympodia (data not shown).

Significant yield response ($P<0.05$) was associated with year, irrigation, irrigation*year and N fertilizer. Fertilized treatments outperformed non-fertilized checks; however, there were no significant differences in yield among fertilizer sources (Table 6). In 2010 and 2011, fertilized and unfertilized check cotton produced similar yields in late start irrigation, but in 2012, fertilizers increased yields compared to the untreated check. Timing of irrigation one week prior to flowering appeared to allow efficient uptake of fertilizer. For all years, data from unfertilized checks were not included in the statistical analysis, N and N*I effects were not significant ($P>0.80$). Irrigation main effects significantly impacted yield. Early start time produced highest yields; rainfed cotton produced lowest yields.

Results from HVI classing data for 50 handpicked boll samples indicate that fiber quality was impacted significantly by irrigation in each year (Table 6). Fiber strength was reduced in early irrigated and rainfed cotton in 2010. Length, uniformity, and strength were reduced in rainfed compared to irrigated cotton in 2011; length, strength, and micronaire were reduced in 2012. Samples from urea and unfertilized treatments had reduced length, uniformity, and strength in 2010. No fiber quality differences were noted in response to N treatments in 2011. Fiber strength and uniformity was reduced in unfertilized cotton in 2012.

Table 6. Mean lint yields[1] from 2010, 2011, and 2012 for the four fertilizer treatments when grown with either early start irrigation, delayed start irrigation, or rainfed (no irrigation).

Fertilizer Source	2010			2011			2012		
	Early	**Late**	**Rainfed**	**Early**	**Late**	**Rainfed**	**Early**	**Late**	**Rainfed**
Urea	1332 ab	1177 bc	938 cde	1339 ab	1105 bc	602 de	1557 ab	1466 ab	454 d
Urea ESN	1465 a	1146 bc	817 de	1433 a	1101 bc	559 e	1618 a	1391 b	506 d
Urea + Biosolids	1369 ab	1183 bc	752 e	1358 ab	1005 c	641 de	1564 ab	1361 b	513 d
Check	928 cde	1043 cd	672 e	854 cd	1047 cd	572 e	1049 c	1070 c	468 d

[1]Means for each year followed by different letters are significantly different ($P=0.05$; LSD_{05}).

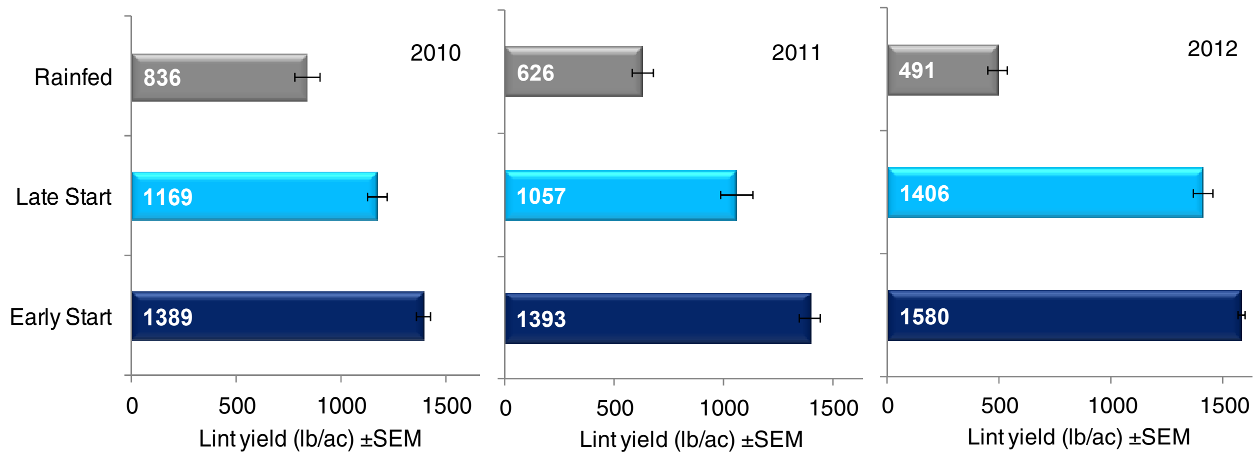

Figure 5. Mean (±SEM) lint yields for fertilized cotton when grown with early and late irrigation start time or with no supplemental irrigation.

Conclusions

Fertilized plants produced similar lint yields regardless of N fertilizer source. Yields were not improved with ESN fertilizer or additions of biosolids under any irrigation regime. Neither fertilizer source improved compensation capacity of plants to recover from pre-flower water deficit stress.

Irrigation and irrigation timing affected fruiting dynamics and yield in all three years. Water deficits induced a range of physiological responses in cotton, and the COTMAN plant monitoring provided an efficient means to document plant response in terms of nodal development, fruit retention and crop maturity. Plants exposed to pre-flower water deficit stress produced fewer main stem fruiting branches by first flowers- this is a key indicator of yield potential. When irrigation start time was delayed until after first flowers, crop plants retained fewer 1st position small bolls compared to early irrigated plants. For the three year study, urea fertilized plants required 12 additional days to reach NAWF=5 compared urea fertilized plants with an early irrigation start time. Mean yield of fertilized plants for the three years was increased from 642 to 1215 lb lint per acre if irrigated. Yields were increased an additional **16%** to 1448 lb if pre-flower water stress was avoided by starting irrigation during early squaring.

If one considers the production *system,* pre-flower water deficit stress delays crop canopy closure, extending weed infestation risk. If irrigation finally is applied at first flower, water stress may be relieved, and as nutrients become available, plants will restart terminal growth. Typically, they also will shed small bolls reallocating photosynthates for the new growth. This compensatory crop growth that occurs after late irrigation prolongs the flowering period and delays cutout. The late crop remains attractive and vulnerable to insect pests such as tarnished plant bug, extending the period the crop must be protected with costly insecticides. Delayed maturity also necessitates use of higher rates of defoliants and boll openers for harvest. Delayed harvest may reduce fiber quality because of prolonged exposure to unfavorable fall weather.

Results from this study indicate that in irrigated Midsouth cotton production, pre-flower water stress avoidance should be a crop management priority for producers aiming for high and early yields. The economic benefit of high yields is obvious; however, the importance of crop earliness cannot be overstated, particularly in the Midsouth. A production strategy that emphasizes crop earliness ultimately improves profitability of cotton production, improves input use efficiencies, and helps protect the environment – all components to a more sustainable cotton system.

Table 6. Means for N fertilizer and irrigation timing effects for HVI classing data for hand-picked 50 boll samples collected throughout consecutive plants -- Judd Hill, AR, 2010, 2011, 2012.

Year	Category	Irrigation timing			Nitrogen fertilizer				*P>F (ANOVA)*		
		Early Start	Late Start	Rainfed	Urea	Urea ESN	Urea + Biosolids	UTC	*Irrigation (I)*	*Nitrogen (N)*	*I*N*
2010	Micronaire	4.75	4.61	4.56	4.58	4.54	4.67	4.77	*n.s*	*n.s*	*n.s*
	Length	1.16	1.18	1.13	1.15	1.17	1.16	1.14	*n.s*	*<.01*	*n.s*
	Uniformity	83.9	84.3	83.6	83.8	84.5	84.0	83.5	*n.s*	*<.01*	*n.s*
	Strength	30.6	31.5	30.0	30.6	31.7	30.8	29.6	*0.03*	*<.01*	*n.s*
	Elongation	6.3	6.5	6.2	6.3	6.3	6.3	6.4	*n.s*	*n.s.*	*n.s.*
2011	Micronaire	5.14	5.20	5.20	5.04	5.15	5.23	5.31	*n.s*	*n.s*	*n.s*
	Length	1.10	1.12	1.01	1.08	1.07	1.08	1.07	*<.01*	*n.s*	*n.s*
	Uniformity	83.6	83.9	81.3	83.1	82.7	83.1	82.8	*<.01*	*n.s*	*n.s*
	Strength	29.7	30.9	27.4	29.5	29.2	29.7	28.9	*<.01*	*n.s*	*n.s*
	Elongation	7.80	7.60	7.60	7.60	7.90	7.70	7.50	*n.s*	*n.s*	*n.s*
2012	Micronaire	5.19	5.11	4.75	4.97	5.03	5.04	5.01	*0.07*	*n.s*	*n.s*
	Length	1.12	1.14	1.04	1.10	1.11	1.10	1.08	*<.01*	*n.s*	*n.s*
	Uniformity	84.3	84.9	81.5	84.2	83.4	83.9	82.9	*<.01*	*0.10*	*n.s*
	Strength	31.2	31.8	30.1	31.4	31.4	31.1	30.2	*n.s*	*0.02*	*n.s*
	Elongation	8.1	8.0	8.1	8.0	8.3	7.9	8.0	*n.s*	*n.s*	*n.s*

[1]Determinations made at Fiber and Biopolymer Research Institute, Texas Tech University, Lubbock., TX.

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